METAL SPAR/SUPERHYBRID SHELL COMPOSITE FAN BLADES

AUGUST 1979

By

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Project Manager, Ray Lark
NASA-Lewis Research Center
Cleveland, Ohio 44135

16. Abstract

This program was undertaken to establish the feasibility of using superhybrid materials for the manufacture and testing of large fan blades. In addition, it was the objective of this program to investigate the FOD resistance of large metal spar/superhybrid fan blades.

The technical effort reported herein was comprised of several elements of work, conducted in series. These elements included:

- Preliminary blade design
- Detailed analysis of two selected superhybrid blade designs
- Manufacture of two process evaluation blades and destructive evaluation
- Manufacture and whirligig testing of six prototype superhybrid blades

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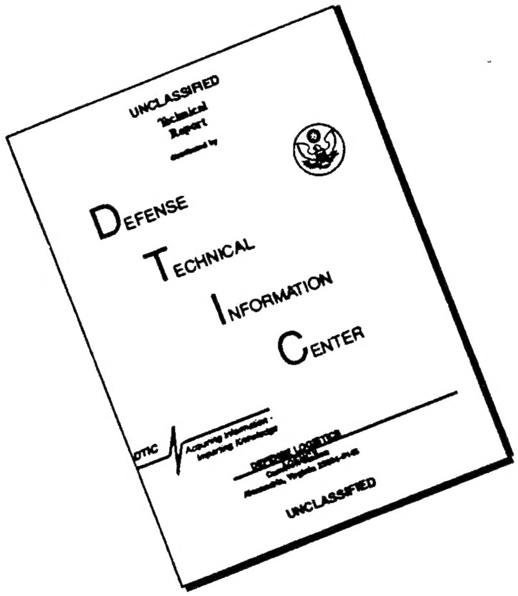

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1.0 SUMMARY

This report presents the results of a 21-month program for the development of superhybrid composite fan blades for application in large, commercial, high-bypass turbofan engines. The full-scale CF6 titanium shrouded fan blade was chosen as the baseline design for the superhybrid blade development since it fit all the requirements of size, application, and tip speed.

The initial effort under Task I was directed at preliminary blade design. Two different blade concepts were considered - an internal spar configuration, designated TiCore, and a leading-edge spar configuration, designated TiCom. The material configurations evaluated for the preliminary blades are specific superhybrid layups as defined in NASA TMX-71836 (Types V and VII).

With NASA concurrence, two designs were selected for detailed design analysis and drawing release.

The detailed 3-D finite-element steady-state analyses of both selected designs were completed. Blade stresses, including spar-to-shell shear and flatwise tensile stresses, were within acceptable limits. Blade frequencies of the unshrouded superhybrid configurations were generally as expected, offering a modest improvement over the baseline unshrouded titanium configuration.

After some initial adjustments in the manufacturing process, two process evaluation blades were successfully molded - one TiCore and one TiCom. Based on destructive analysis of the TiCom blade, approval was given to proceed with the fabrication of six whirligig test blades. All of the six superhybrid blades were successfully manufactured, and their overall quality was verified in a full Material Review Board (MRB) review. All blades were judged acceptable for testing. Final blade weights indicate that the superhybrid blades would weigh 27 to 30% less than the baseline titanium blade. The whirligig test program for the superhybrid blades consisted of 100-cycle spin testing of one blade from each of the two designs at 110% of design speed. After successful completion of this testing, whirligig bird impact testing was conducted on four of the six test blades. Test results of the first two blades from starling impact showed that the TiCore blades suffered the lesser damage and that this was limited to the attachment of the nickel plate to the wire mesh. The TiCom blade suffered considerably more: its spar separated from the shell, causing a sizable delamination.

Further testing of the remaining TiCom blades was discontinued. Three additional tests were conducted on the TiCore blades, however, and it was during this subsequent testing that the only shortcoming of the TiCore blade design was found, namely poor adhesion of the nickel-plate leading-edge protection system. This is not a major problem and is believed to be solvable by improving the nickel-plate leading-edge process or by substituting a suitable alternate leading-edge protection system.

This program demonstrated that the superhybrid material concept is a feasible one which can be utilized to produce high quality large fan blades having good structural integrity. The manufacturing process developed during this program demonstrated that several prototype blades could be manufactured with good uniformity and dimensional control, and that the process is capable of being scaled up for preproduction quantities of blades. While whirligig testing confirmed that both the TiCore and TiCom blade designs are feasible from the standpoint of steady-state operating conditions, it clearly demonstrated the superior bird-impact resistance of the TiCore blade.

2.0 INTRODUCTION

In the last decade, high-bypass turbofan engines have become the standard power plant for subsonic aircraft because of their high thrust-to-weight ratios and low fuel consumption. The cost and weight of the engines is strongly influenced by the fan because of its large size and weight compared to the rest of the engine. Any major improvement in the fan can significantly reduce life cycle costs for subsonic aircraft. Composite fan blades have the potential of making major improvements in the fan with improvements in cost, weight, efficiency, and maintenance.

When the superhybrid composite material concept was identified by NASA a few years ago (NASA TND-7879 and NASA TMX-71836), it opened a new dimension in materials technology. A variety of structural reinforcements could now be combined into a single material structure, with each contributing its unique features.

The use of this material concept in large fan blades offers a unique design alternative to previous metallic and composite blade designs. The superhybrid composite combines the strength and weight features of the polymeric materials, the high stiffness characteristics of boron/aluminum, and the local impact toughness of titanium. This is achieved by combining all three materials in a unique arrangement, using adhesive as the binder and closed-die molding techniques to form the blade shape.

This program was undertaken to establish the feasibility of using such a material system for the manufacture and testing of superhybrid blades. In addition, it was the objective of this program to investigate the FOD resistance of large metal spar/superhybrid fan blades.

The technical effort under this program was composed of several work elements conducted in series, including:

- Preliminary blade design
- Detailed analysis of two selected superhybrid blade designs
- Manufacture and destructive evaluation of two process evaluation blades
- Manufacture and whirligig testing of six prototype superhybrid blades

3.0 BLADE DESIGN

3.1 BASELINE BLADE DESIGN

The CF6 blade was selected as the configuration to demonstrate the feasibility of the superhybrid material concept in this program. This blade configuration met all the requirements necessary to prove out the superhybrid concept for large fan blades and was believed to promise the weight, containment, and FOD resistance payoffs associated with the superhybrid material. Other benefits associated with the CF6 fan blade selection were:

- It is a high-tip-speed [1500 ft/sec (457.2 m/sec)] configuration currently in commercial service.
- The CF6 aerodynamic design is being used in other composite blade programs, including the F103 graphite hybrid fan blade (AF5072) and the design of a CF6 boron/aluminum fan blade (NAS3-21041).
- Titanium CF6 blades were readily available for use in machining titanium spars for this program.
- Existing whirligig test rig hardware was available that would accept the CF6 superhybrid blade.

The titanium blade configuration is shown in Figure 1. There are 38 blades in the rotor assembly. The blade has a 30-inch (0.762 m) length, a 9.8-inch (0.249 m) tip chord, and a 6.5-inch (0.165 m) root chord. The overall blade weight is 11.0 pounds (4.99 kg); this represents the baseline blade weight used for comparison with blades made in this program. The airfoil geometry used for the superhybrid blade was the same as the CF6 titanium fan blade with the midspan shroud removed.

The CF6 metal blade aero design definition is presented in Table I. The detailed geometry as a function of radial blade height is compared with that of the F103 polymeric composite blade in Figure 2.

3.2 PRELIMINARY BLADE DESIGN

3.2.1 Blade Design Configurations

Two basic blade design configurations were selected for evaluation in this program. Both designs utilize metallic spars with full-length, as-designed CF6 dovetails. The first design is a standard spar/shell design designated TiCore. This design, shown schematically in Figure 3, shows the typical spar configuration which is completely internal to the shell.

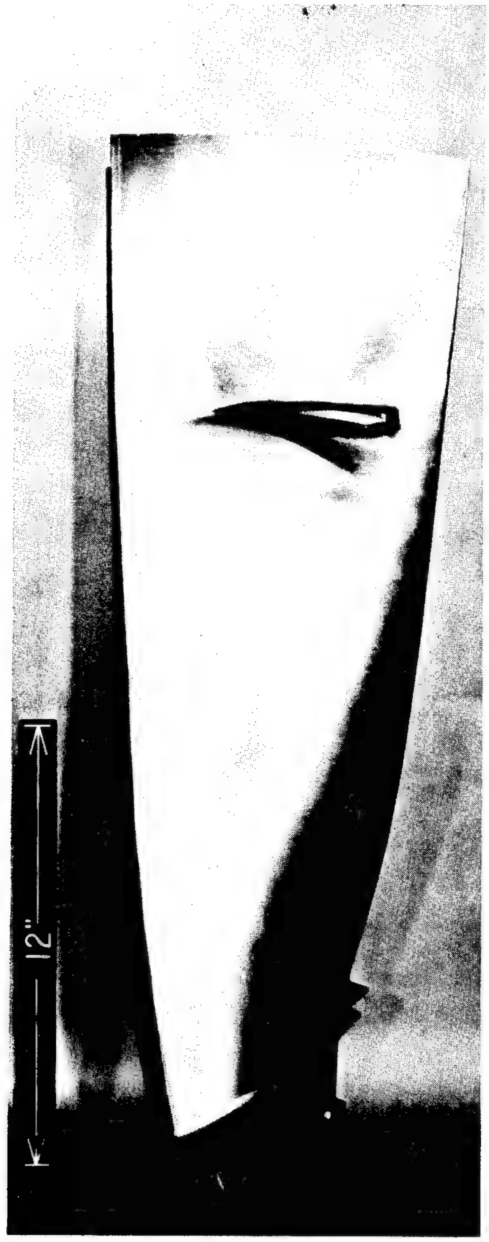


Figure 1. CF6 Titanium Blade.

Table I. CF6 Titanium Blade Geometry.

Number of Blades	38
Maximum Steady-State, rpm	4080
Tip Speed, ft/sec (m/sec)	1512 (460.8)
Tip Radius, in. (m)	42.48 (1.079)
Tip Chord, in. (m)	9.8 (0.249)
Root Chord, in. (m)	6.43 (0.163)
Tip Solidity	1.39
Root Solidity	2.2
Tip Tm/C	0.025
Root Tm/C	0.089
Tip Thickness, in. (m)	0.245 (6.22×10^{-3})
Root Thickness, in. (m)	0.57 (0.145×10^{-3})
Airfoil Weight, lbm (kg)	8.1 (3.674)
Blade Weight, lbm (kg)	10.8 (4.899)
Root Center Force, lb (newtons)	103,000 (458,166)
Root Center Stress, ksi (n/m^2)	37,000 (2.551×10^8)
Root Area, in.^{2} (m^2)	2.8 (1.806×10^{-3})
Airfoil Peak Stress, ksi (n/m^2)	67,000 (4.619×10^8)
Location of Airfoil Peak Stress	Midchord Root
Maximum Shear Stress Root, ksi (n/m^2)	N.A.
1T Frequency, cps (hz)	460 (460)
Material	Ti 6-4

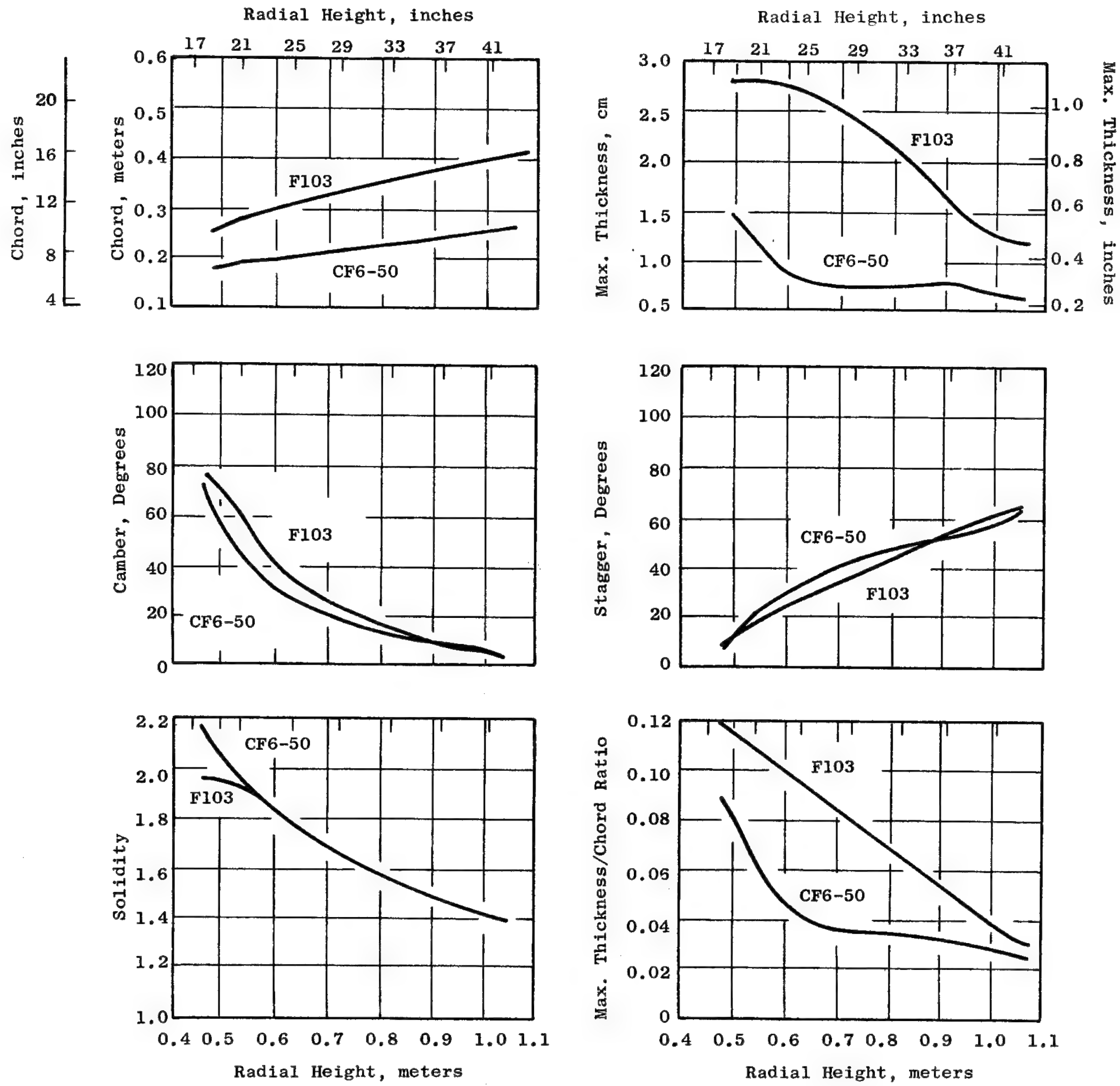


Figure 2. Comparison of CF6-50 Titanium and F103 Polymeric Composite Blade Geometry.

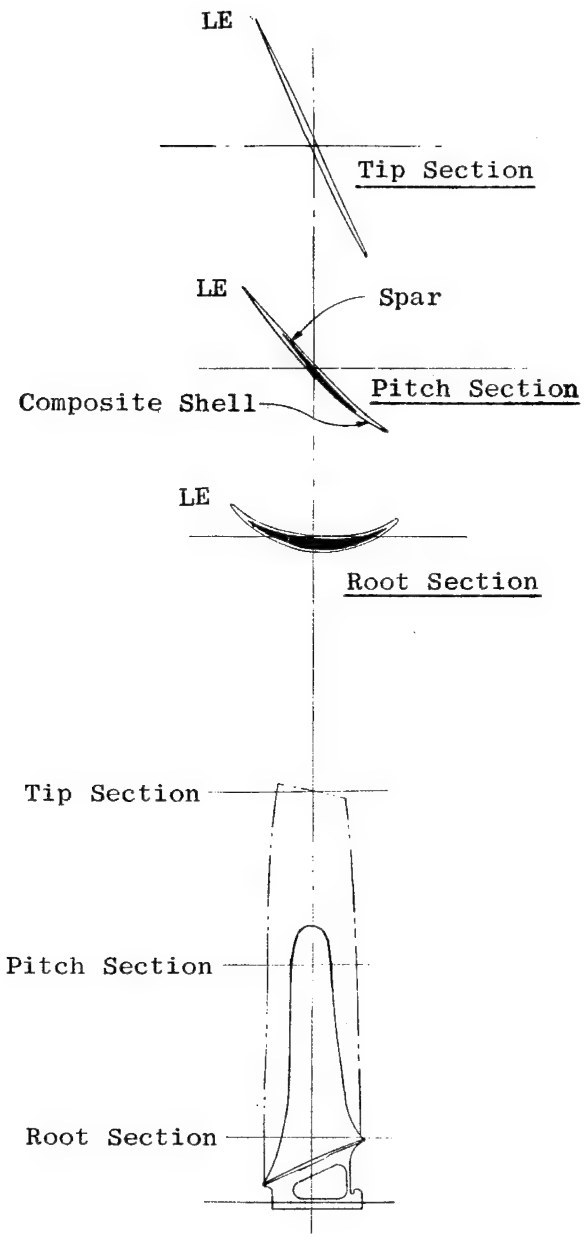


Figure 3. Schematic of Standard Spar Design (TiCore).

The second configuration evaluated in this program is one having the metal spar shaped in such a way to provide spar material at the leading-edge concave side where it can have a direct benefit in dissipating the local impact forces from a variety of foreign objects including birds. A schematic of this design designated TiCom is shown in Figure 4.

3.2.2 Superhybrid Material Configurations

During the preliminary design phase of this programming, two superhybrid material configurations were evaluated analytically in combination with each of two previously described spar/shell blade designs. The two material combinations considered are shown in Figures 5 and 6. The layup typical of Types V and VII that is shown in these figures was developed by NASA and is described in NASA TN D-7879 and TM X-71836.

The major differences in the two layup configurations is the absence of center titanium plies in the Layup VII configuration. In the actual blade designs (to be discussed in later sections) the Layup V configuration was found unnecessary as a result of having an internal spar in the blades.

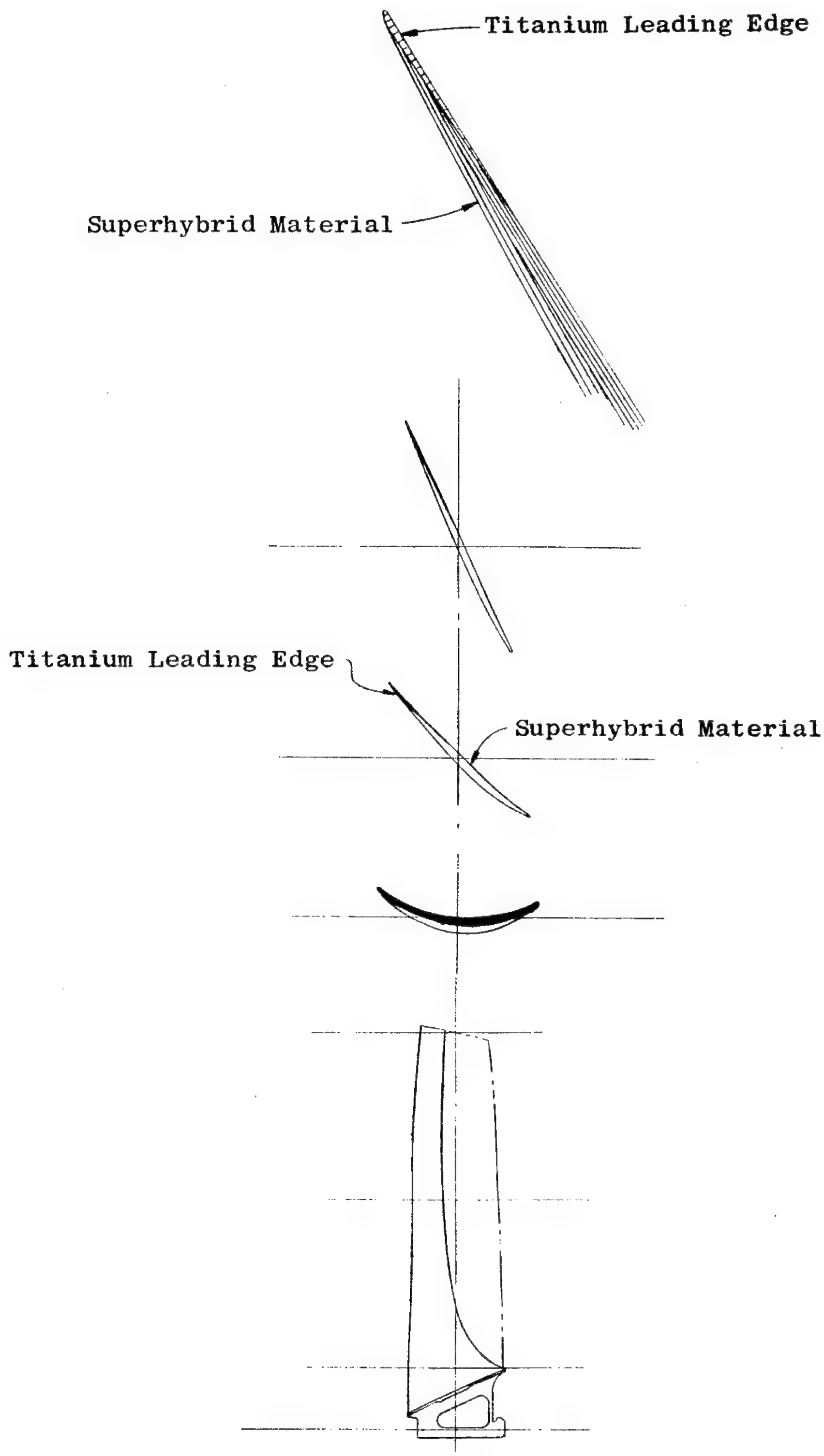
One of the outstanding characteristics which provided the incentive to select these particular superhybrid material layups is illustrated in Figure 7. In this figure, the longitudinal flexural strength is plotted versus the transverse flexural strength. For both of the superhybrid layup configurations (V and VII), the transverse flexural strength is on the order of 40 to 50% of the longitudinal strength.

From an impact standpoint, this high transverse strength is extremely desirable. In conventional polymeric composites, most of the fibers are aligned in the longitudinal direction to provide adequate radial strength. As a result, the transverse or chordal strength is low. The superhybrid composite materials exhibit 2 to 2.5 times the polymeric chordal strength while retaining a high longitudinal strength.

3.2.3 Design Conditions

The design conditions established for the superhybrid blades are basically those used for the mechanical design of the CF6 metal blade. No consideration was given, however, to blade LCF analysis or life prediction. The specific design conditions are:

- Steady state operation at 4080 rpm (100% speed)
- Maximum overspeed condition: 120% speed (operate for 5 minutes)
- Allowable stresses at 100% speed must be less than 70% of material strengths



Concave Side/Leading Edge Spar

Figure 4. Schematic of CF6 Superhybrid Composite Blade Design (TiCom).

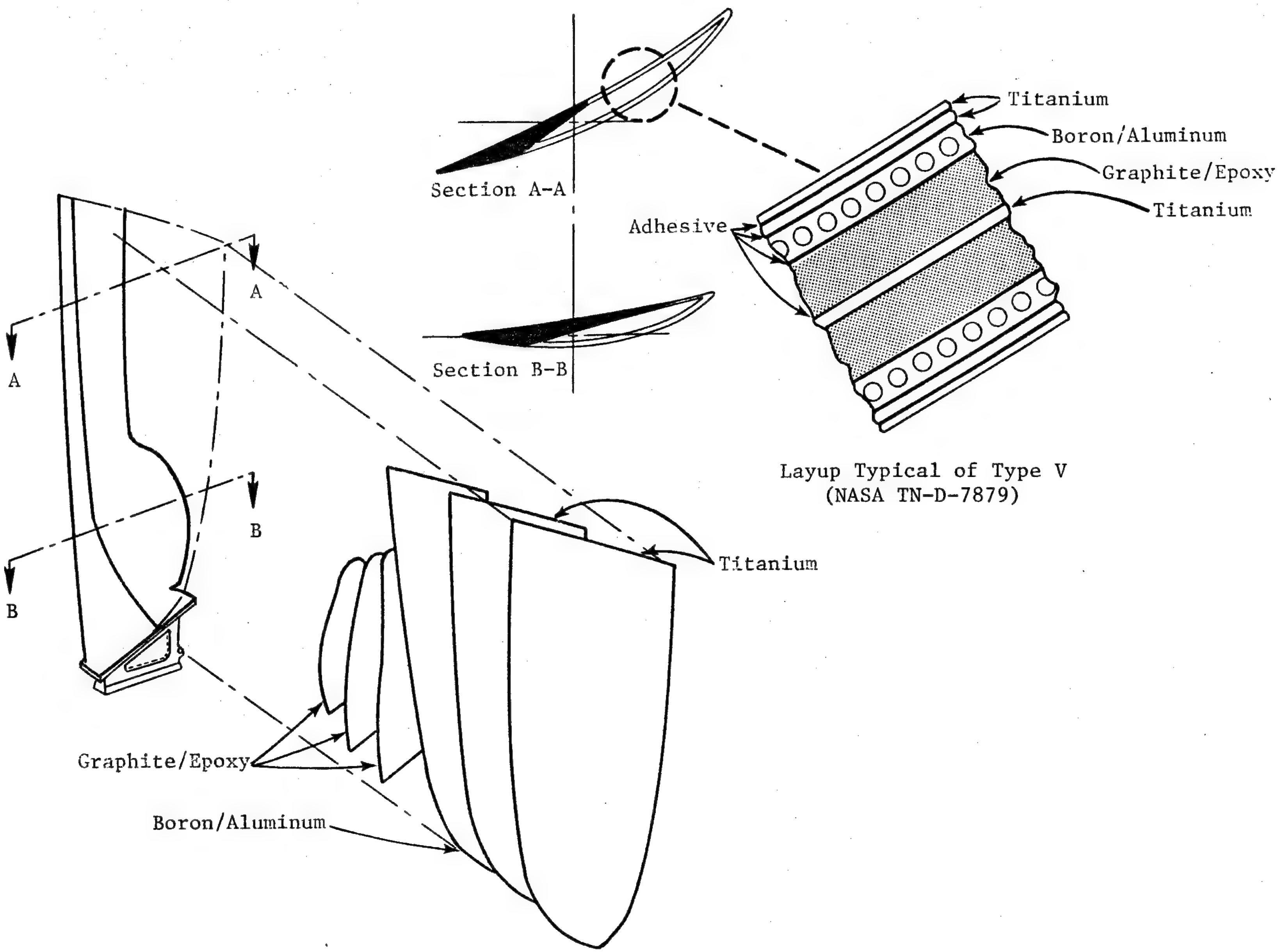


Figure 5. Candidate Blade Design Showing Leading Edge Spar and Type V Superhybrid Composite Layup.

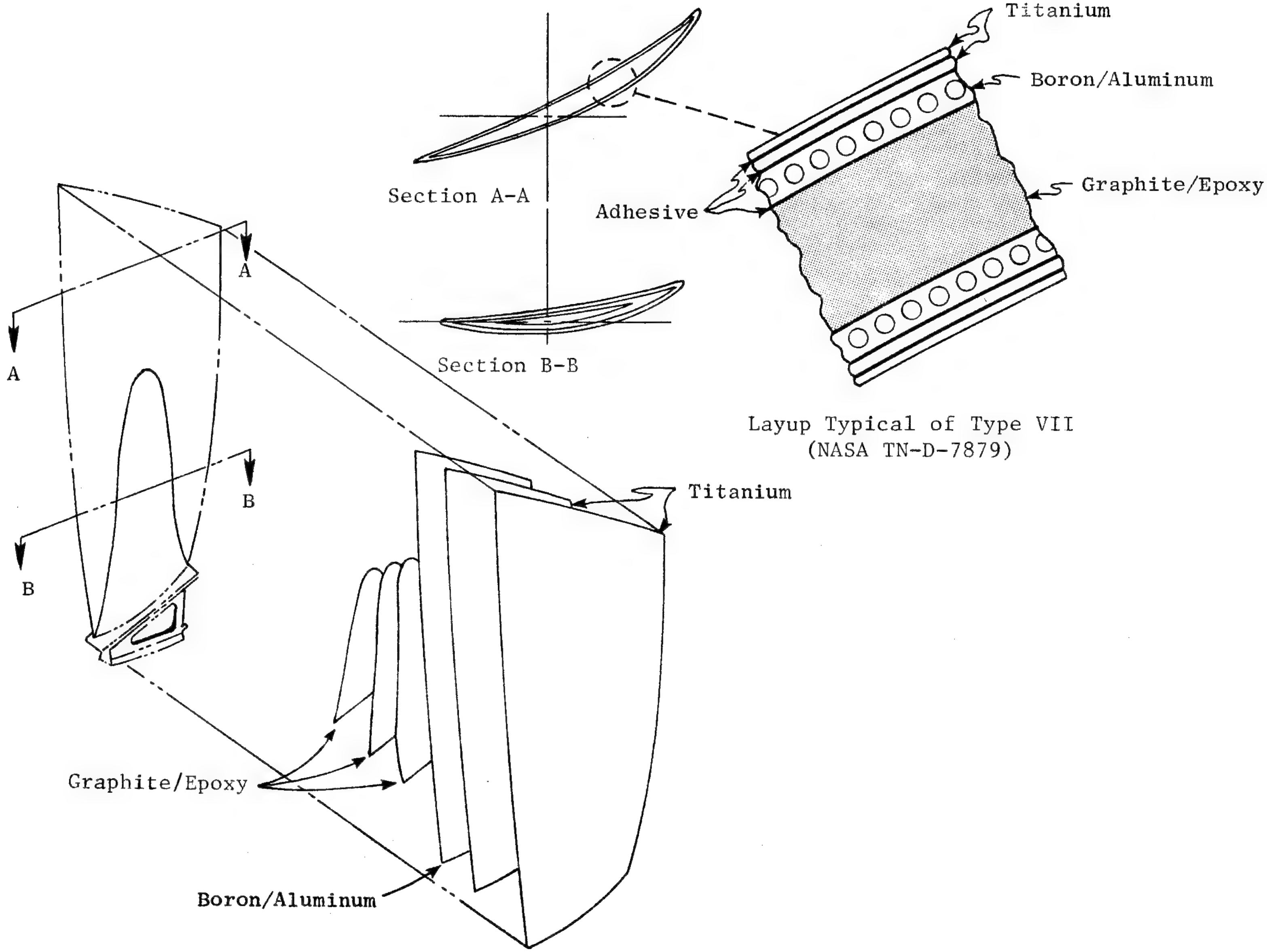


Figure 6. **Candidate Blade Design Showing Internal Spar and Type VII Superhybrid Composite Layup.**

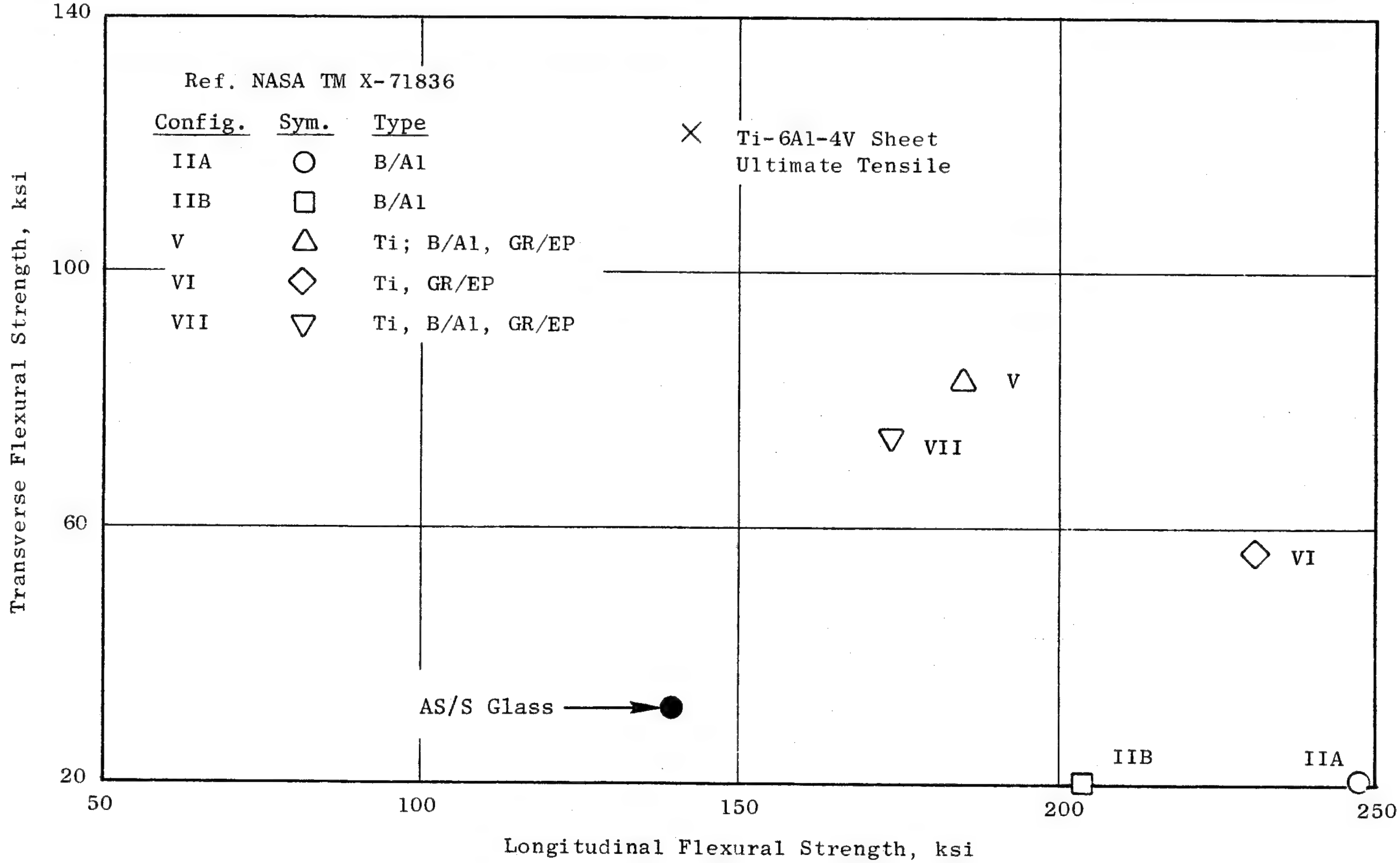


Figure 7. Flexural Strength of Composites and Superhybrid Composites.

3.2.4 Design Analysis

The preliminary design analysis was directed toward the evaluation of four designs in terms of weight payoff, steady-state stress, frequency characteristics, and FOD potential.

Two TiCom leading-edge spars and two internal-spar configurations were designed, each design featuring a superhybrid composite shell. All designs were based on using an existing unshrouded CF6 blade as the basis for spar manufacture.

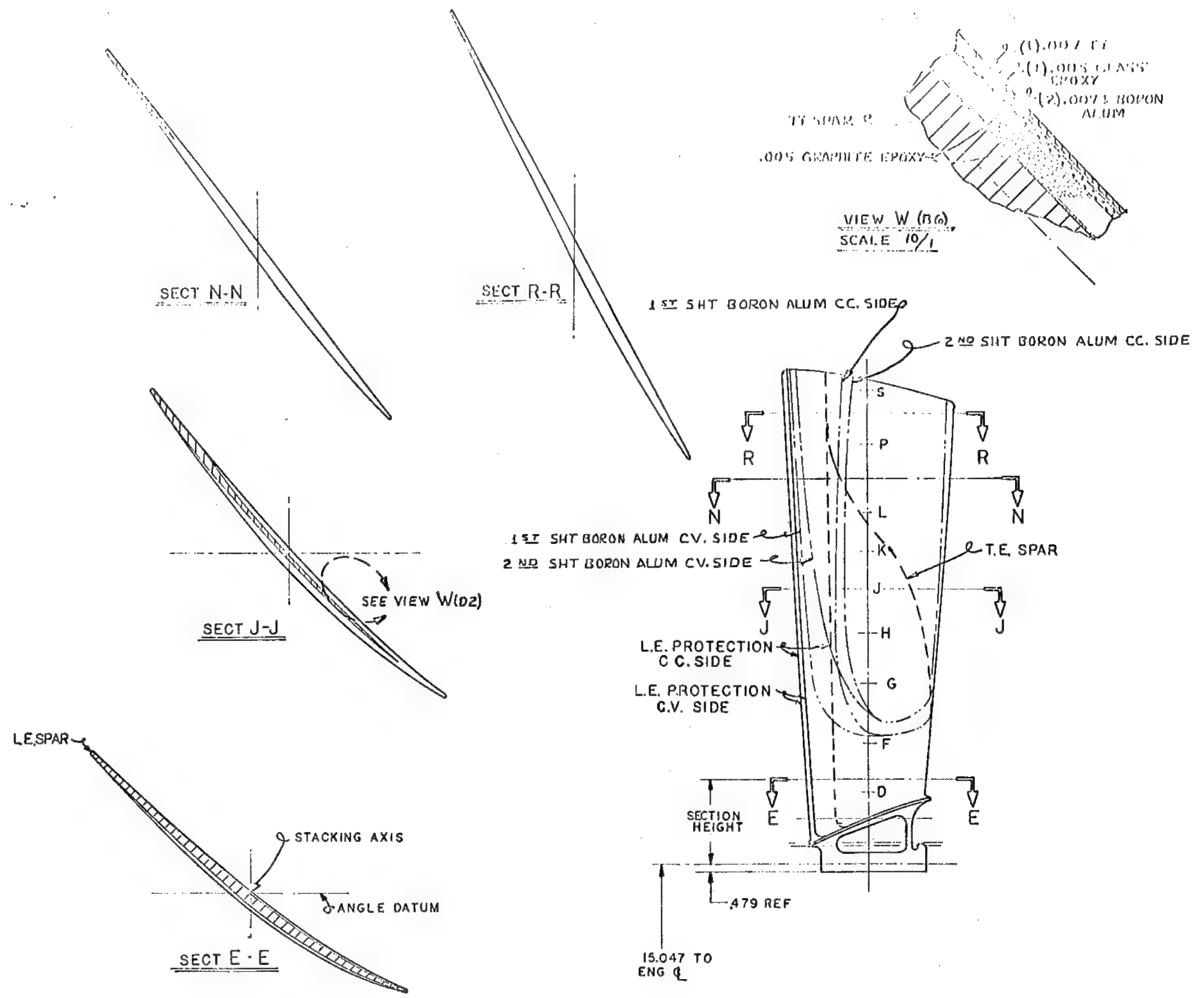
In the TiCom concept, the titanium spar is placed at the leading edge of the blade and transitions into the root attachment, while the superhybrid composite materials comprise the bulk of the airfoil. In the internal spar design, the spar is entirely contained within the blade with the composite shell forming the outside of the blade. The four preliminary designs selected are shown in Figures 8, 9, 10, and 11.

Figures 8 and 9 present the two TiCom designs considered. Those two designs represent what is considered to be the extremes of the range of practical spar sizes, because the small spar is limited by leading-edge FOD protection considerations in the upper airfoil. The large spar is limited by weight considerations and has only a very small weight payoff over a titanium blade. The two internal-spar designs are shown in Figures 10 and 11. Again, a small spar and a large spar were considered. Figure 12 shows a detail of the superhybrid ply layup for all designs. The outside of the superhybrid layup is one ply of 0.007-inch (1.778×10^{-4} m) thick titanium 6-4 foil. Two plies of 5.6-mil (1.422×10^{-4} m) boron/1100 aluminum are placed inside the surface titanium ply. A 5-mil (1.270×10^{-4} m) ply of S-glass epoxy is placed on both sides of the boron/aluminum material to prevent any long-term galvanic corrosion problems. The bulk of the superhybrid is composed of AS graphite/epoxy material. Table II presents a summary of the important design parameters for the four designs. Also included in Table II are some data on an all-titanium blade.

Several observations may be made concerning the results shown in Table II.

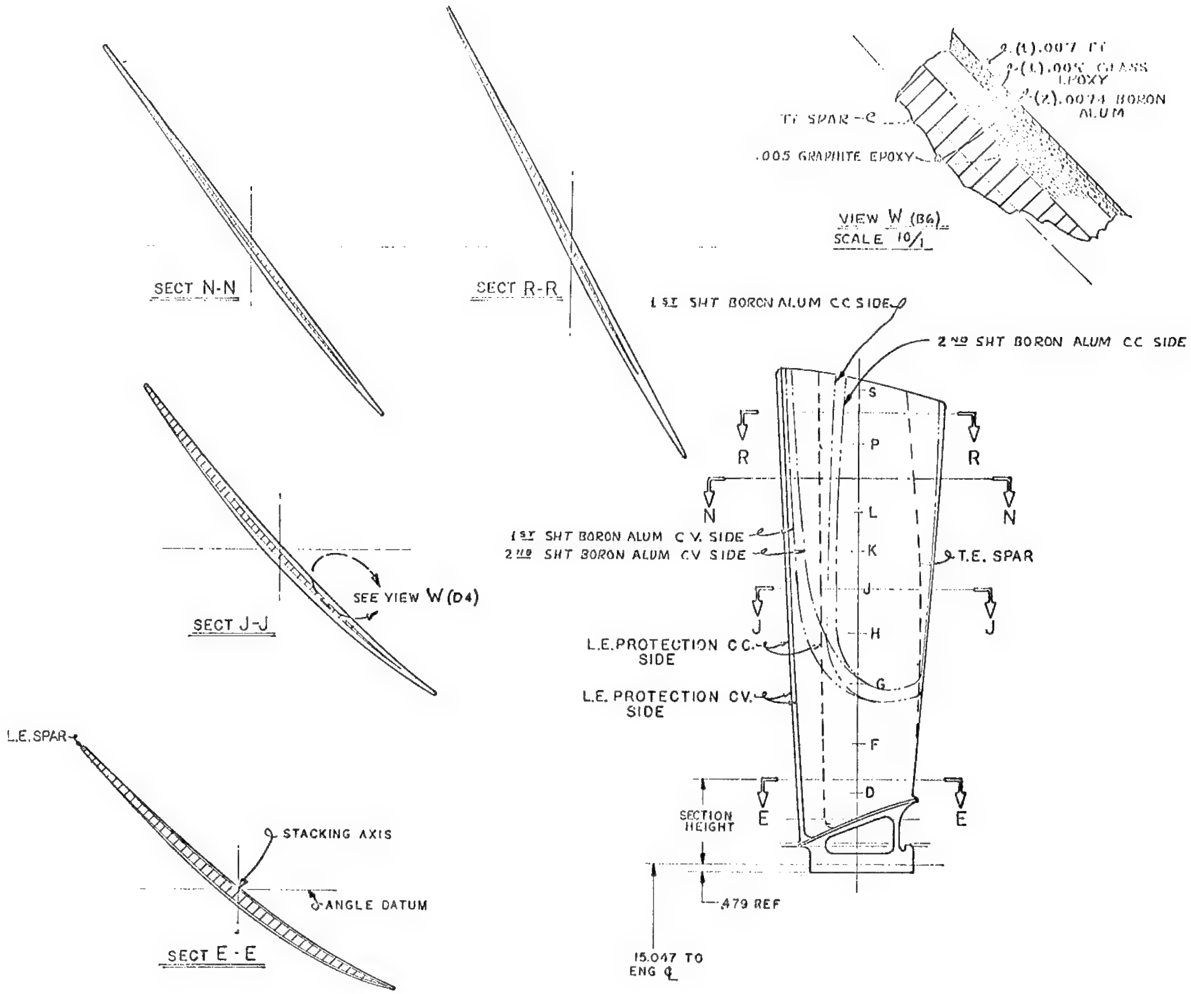
- The weight benefits of the spar/shell designs compared to an all-titanium blade can be substantial, especially if small spars can be employed.

- Frequency characteristics of all the superhybrid spar/shell blades are similar to the all-titanium cantilevered blade but are greatly reduced relative to a midspan-shroud-supported blade. Of particular interest is the low first torsional frequency of 150 Hz versus a midspan-supported titanium blade value of 426 Hz. For a blade of this size to be aeromechanically (flutter) acceptable, a first torsional frequency near the 426 Hz level is required. For engine operation, the current cantilevered blade design would be changed by increasing the chord and/or maximum thickness of the blade and reducing the number of blades per stage.



SECTION	SECTION HEIGHT	ENGRE MASTER
A-A	.784	4013057-743
B-B	1.060	
C-C	2.644	
D-D	4.044	
E-E	4.769	
F-F	6.710	
G-G	10.182	
H-H	13.044	
J-J	15.497	
K-K	17.745	
L-L	19.891	
M-M	20.096	
N-N	21.836	
P-P	23.778	
R-R	25.517	
S-S	26.848	
T-T	27.354	
U-U	27.912	
V-V	28.178	

Figure 8. Small Spar TiCom.



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B-B	1.060	
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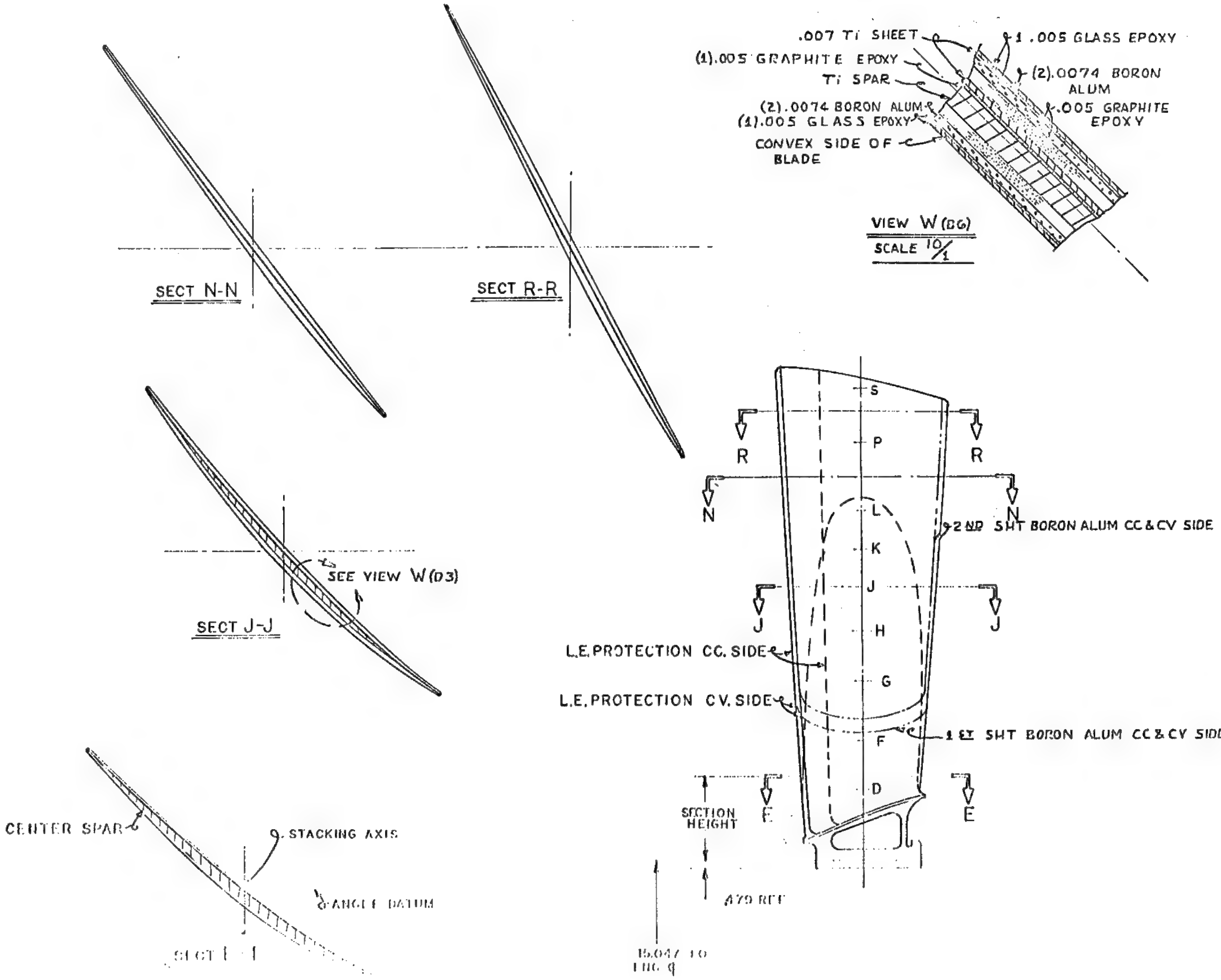
T-T	27.354	
U-U	27.912	
V-V	28.178	

Figure 9. Large Spar TiCom.



SECTION	SECTION HEIGHT	ENGRE MASTER
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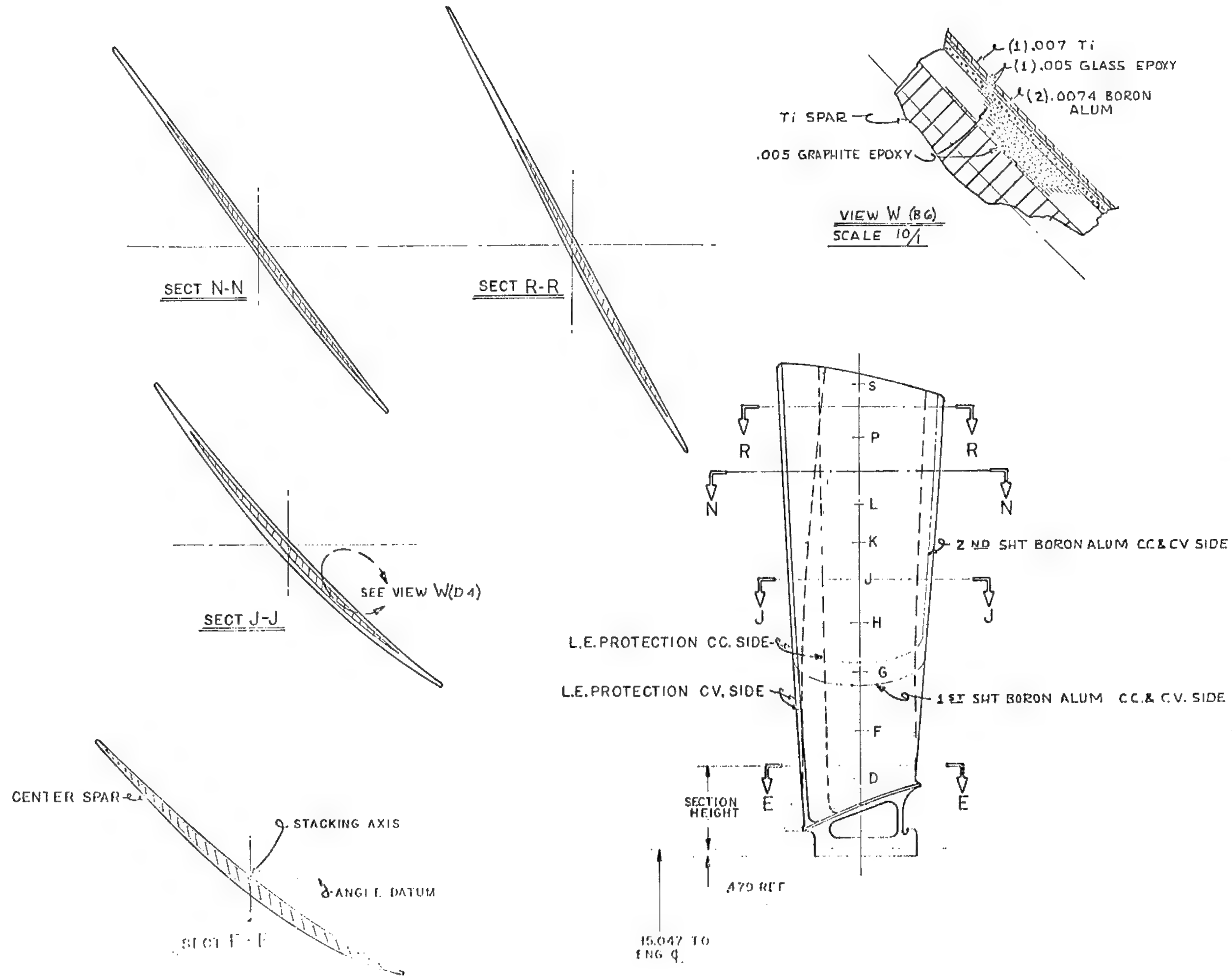
S-S	26.848	
T-T	27.354	
U-U	27.912	
V-V	28.178	

Figure 10. Small Internal Spar.



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P-P	23.778	
R-R	25.517	
S-S	26.848	
T-T	27.354	
U-U	27.912	
V-V	28.178	

Figure 11. Large Internal Spar.

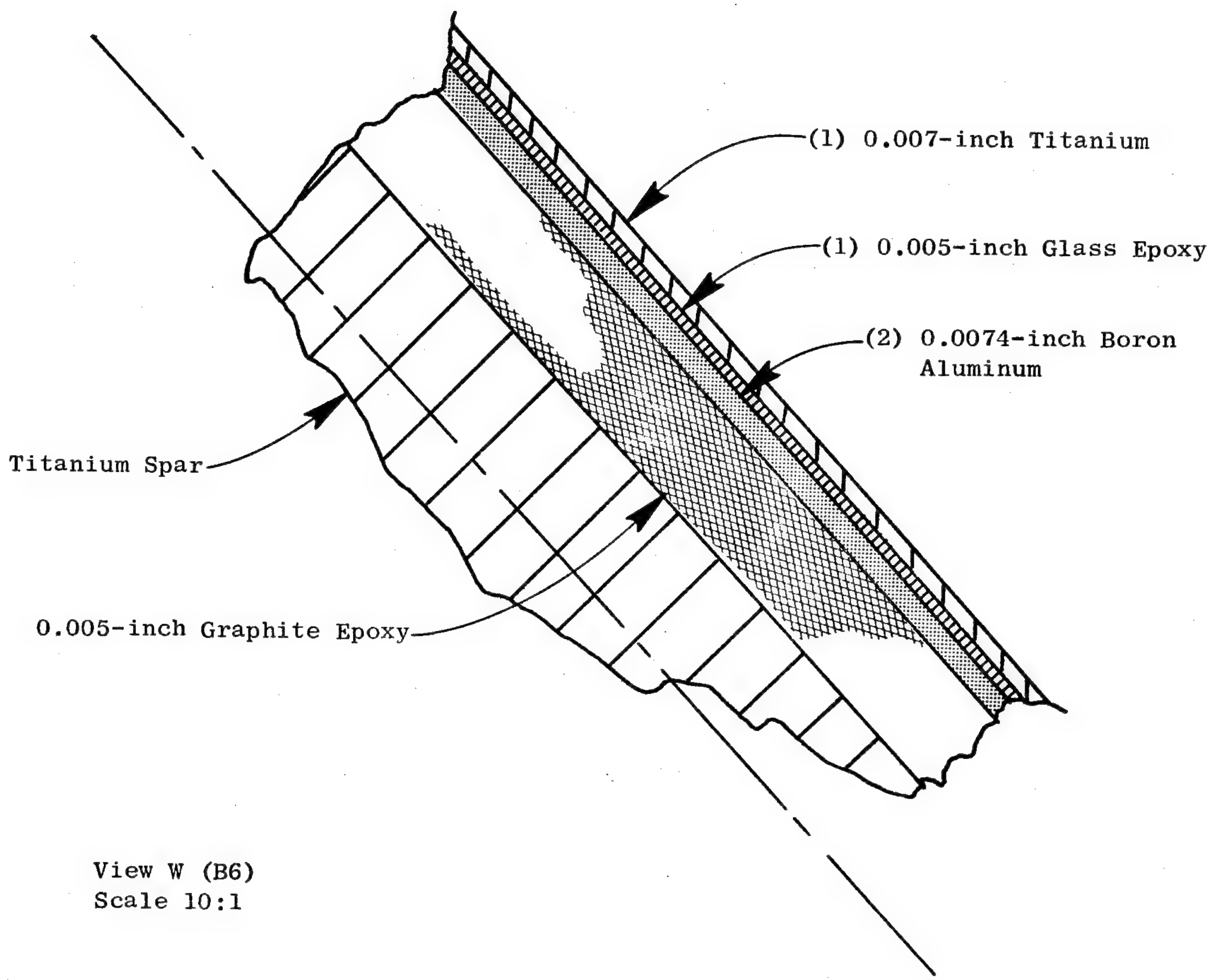


Figure 12. Superhybrid Composite Layup Detail.

Table II. Blade Design Summary.

Design	Type	Δ Weight,** lb (kg)	Estimated Bench Frequencies, Hz		Layup Angles		Shear Stress, ksi (n/m^2)	Centrifugal Stress	
			1st Flex.	1st Tors.	B/Al	AS		Max Compression ksi (n/m^2)	Max Tension, ksi (n/m^2)
1	Small TiCom	-2.2 (0.998)	35	150	±15°	±0°, ±35°	0.6 (4.136×10^6)	27 (1.86×10^8)	30 (2.07×10^8)
2	Big TiCom	-1.7 (0.771)	35	150	±15°	±0°, ±35°	0.7 (4.826×10^6)	29 (2.0×10^8)	33 (2.27×10^8)
3	Small Internal	-2.0* (0.907)	35	150	±15°	±0°, ±35°	0.5 (3.447×10^6)	29 (2.0×10^8)	25 (1.72×10^8)
4	Big Internal	-1.2* (0.544)	35	150	±15°	±0°, ±35°	0.6 (4.136×10^6)	36 (2.48×10^8)	32 (2.21×10^8)
	All-Titanium Cantilevered	0	22	152					
	All-Titanium Shrouded	0	202	426					

*Includes 0.5-lb (0.226 kg) Leading-Edge Protection.
**Relative to Ti Cantilevered.

- The steady-state centrifugal stress and spar-to-shell shear stress were evaluated for each design. The maximum stress values are shown in the last three columns of Table II. All the calculated stresses are well within the design allowables shown in Table III. Under impact conditions, however, much higher stresses than those calculated will be present; therefore, considerable margin on steady-state stress is desirable. Also, the effects of bending were not included in the preliminary design analysis. These effects were evaluated in the TAMP finite-element analysis of the two selected designs. The TAMP analysis is discussed in a later section.

After the preliminary design review with NASA was conducted, it was agreed that one TiCore and one TiCom superhybrid blade design would be selected. The small internal-spar design (Figure 9) was selected, chiefly for its substantial weight benefit. For the TiCom design, it was decided that an intermediate-size spar (Figure 13) would offer the best tradeoffs between weight reduction and FOD benefits. This design had an estimated weight reduction of 1.9 lb (0.862 kg) compared to the all titanium blade. Prior to blade fabrication, these two designs underwent more detailed studies, including a TAMP stress analysis.

3.3 DETAILED DESIGN ANALYSIS

3.3.1 Finite-Element Model

The finite-element model used to carry out the detailed analysis incorporated 306 elements and 504 nodal coordinates. The finite-element definition was established to represent both the TiCore and TiCom blades in a single model. Having three elements through the thickness made it possible to represent the titanium/boron/aluminum skins, the graphite/epoxy core, and the titanium spar individually and in combination in the analysis. Figure 14 shows the finite-element model as projected on the Y-Z coordinate plane. The analysis was conducted in a centrifugally stiffened field representing the 100% design speed of 4080 rpm, but did not include air loads, as this loading generally produces a negligible affect on blade stresses.

3.3.2 Material Properties

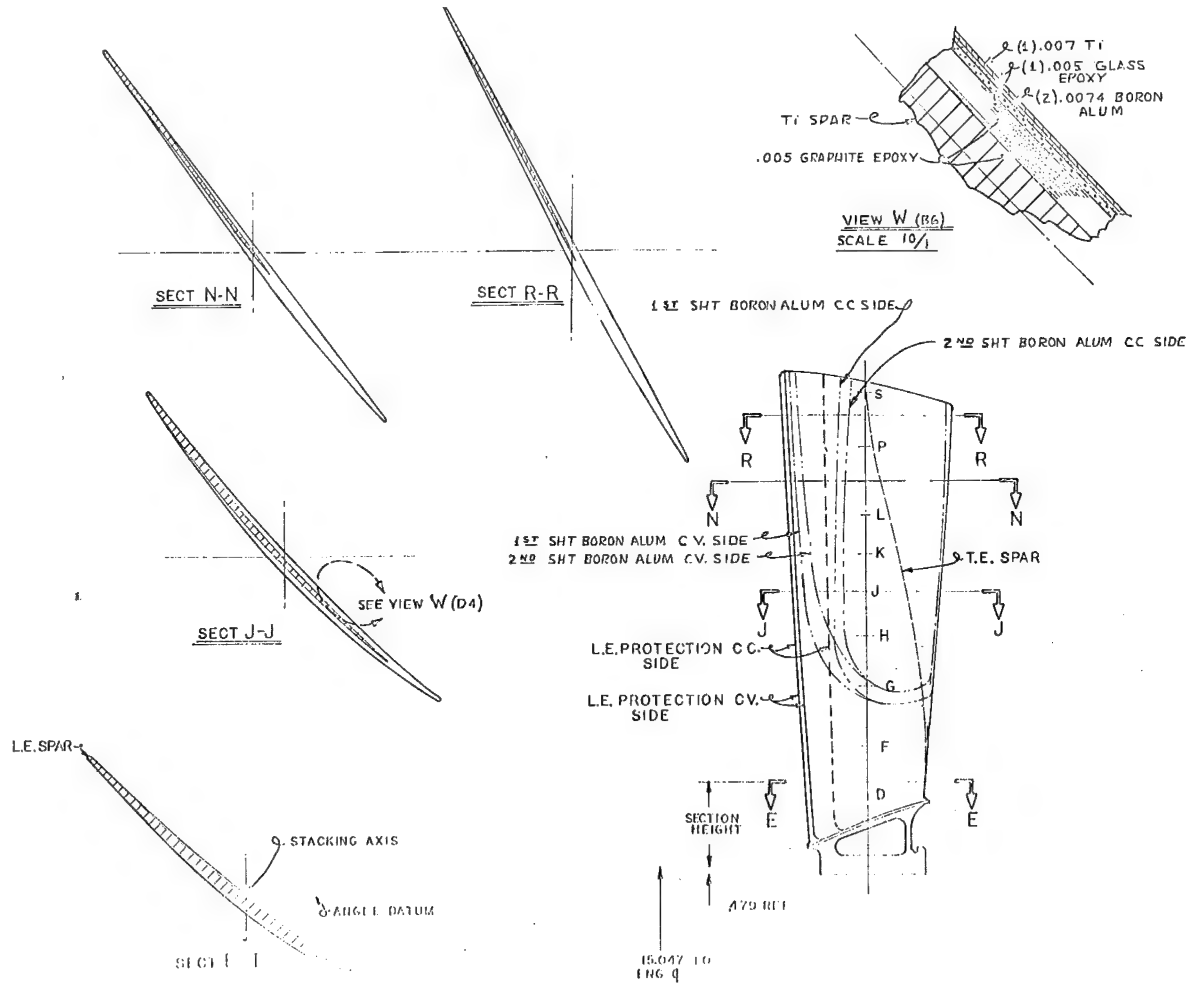
The material properties used to generate the data for the finite-element model are summarized in Table IV. The superhybrid Configuration VII material presented is a combination of titanium (8%), boron/aluminum (21%), and graphite/epoxy (71%) properties.

3.3.3 Stress Analysis Results

The results of the detailed stress analysis for both the TiCore and TiCom superhybrid blades are presented in Figures 15 through 26. The peak stresses extracted from these figures are summarized in Table V. These data

Table III. Material Allowables at 4080 rpm.

	Tensile, ksi (n/m^2)		Bending, ksi (n/m^2)		Shear, ksi (n/m^2)
	0°	90°	0°	90°	
Titanium	90	---	90	---	50 (3.45×10^8)
Superhybrid	92	16 (1.10×10^8)	120	51 (3.51×10^8)	---
Spar/Shell Bond	---	---	---	---	2 (1.35×10^7)



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V-V	28.178	

Figure 13. Fan Rotor Superhybrid Blade - Intermediate Leading-Edge Spar.

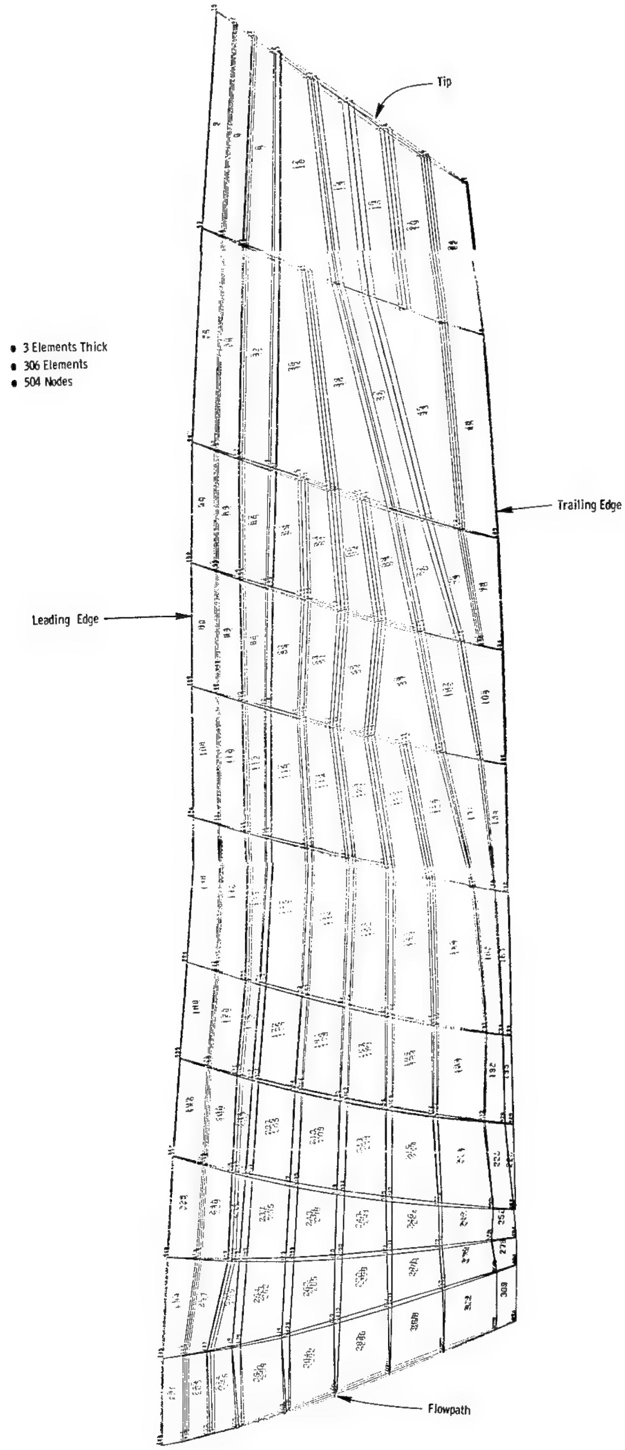


Figure 14. TAMP Model.

Table IV. TAMP Superhybrid Material Properties.

	Titanium 6-4	B/Al ±15°	Graphite/ Epoxy 0 ± 35°	Superhybrid Configuration VII
Through-Thickness Tensile Modulus, E_{11} - 10^6 psi (10^{10} n/m^2)	16.0 (11.03)	10.6 (7.31)	1.5 (1.03)	4.6 (3.17)
Chordal Tensile Modulus, E_{22} - 10^6 psi (10^{10} n/m^2)	16.0 (11.03)	19.0 (13.10)	1.65 (1.14)	6.4 (4.41)
Radial Tensile Modulus, E_{33} - 10^6 psi (10^{10} n/m^2)	16.0 (11.03)	26.0 (17.92)	10.6 (7.31)	14.3 (9.86)
Chordal Shear Modulus, G_{12} - 10^6 psi (10^{10} n/m^2)	6.2 (4.27)	6.0 (4.13)	0.7 (0.483)	2.3 (1.59)
Cross-Fiber Shear Modulus, G_{23} - 10^6 psi (10^{10} n/m^2)	6.2 (4.27)	10.1 (6.96)	2.35 (1.62)	4.3 (2.96)
Radial Shear Modulus, G_{13} - 10^6 psi (10^{10} n/m^2)	6.2 (4.27)	6.0 (4.13)	0.7 (0.483)	2.3 (1.59)
Chordal Plane Poisson's Ratio (M_{12})	0.3	0.3	0.3	0.3
Cross-Fiber Plane Poisson's Ratio (M_{23})	0.3	0.34	0.62	0.54
Radial Plane Poisson's Ratio (M_{13})	0.3	0.24	0.3	0.29
Density, lb/in.^{3} (kg/m^3)	0.161 (4456)	0.10 (2768)	0.06 (1661)	0.076 (2104)

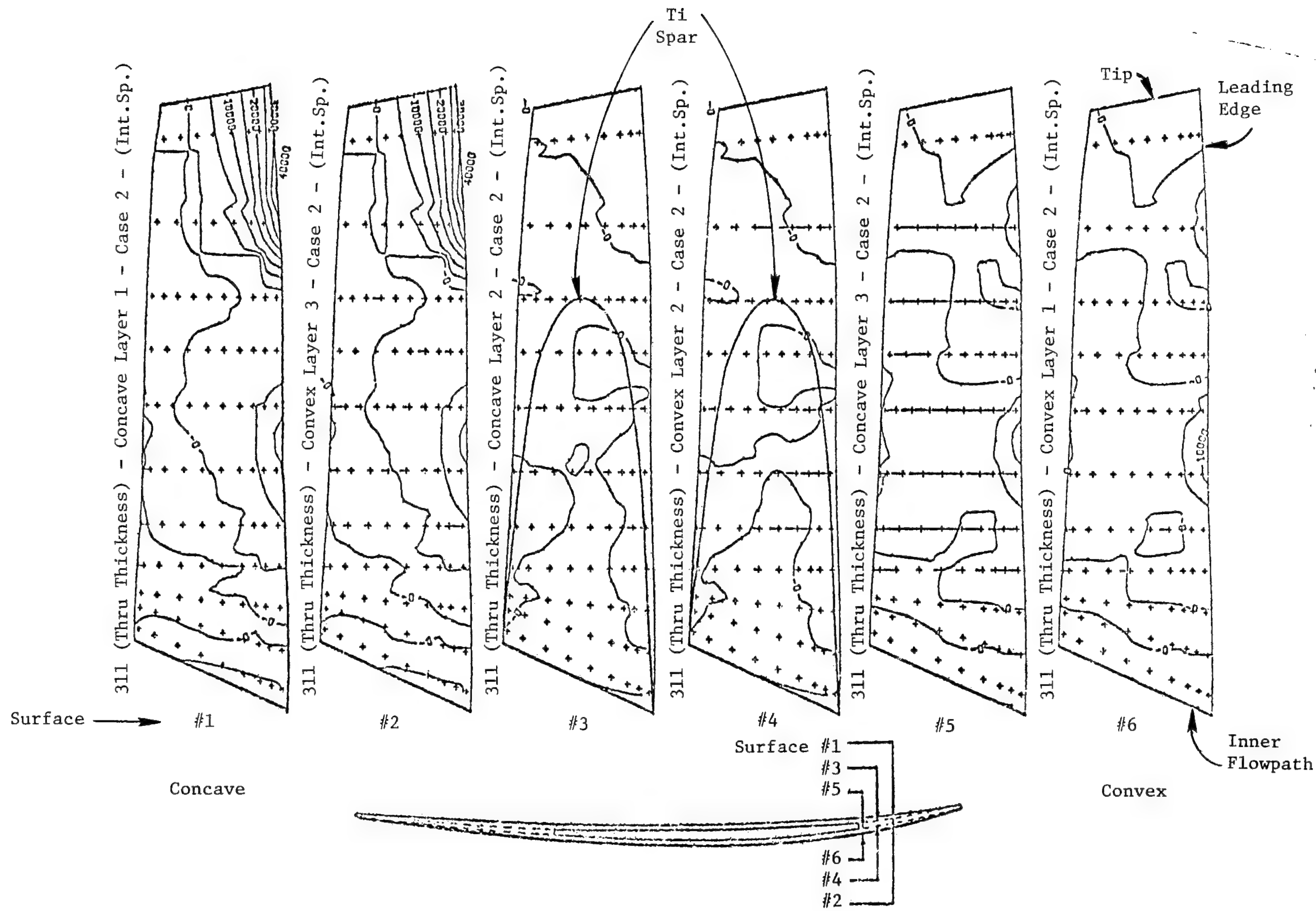


Figure 15. Internal Spar Blade TAMP Flatwise Tensile Stress (psi), 4080 rpm.

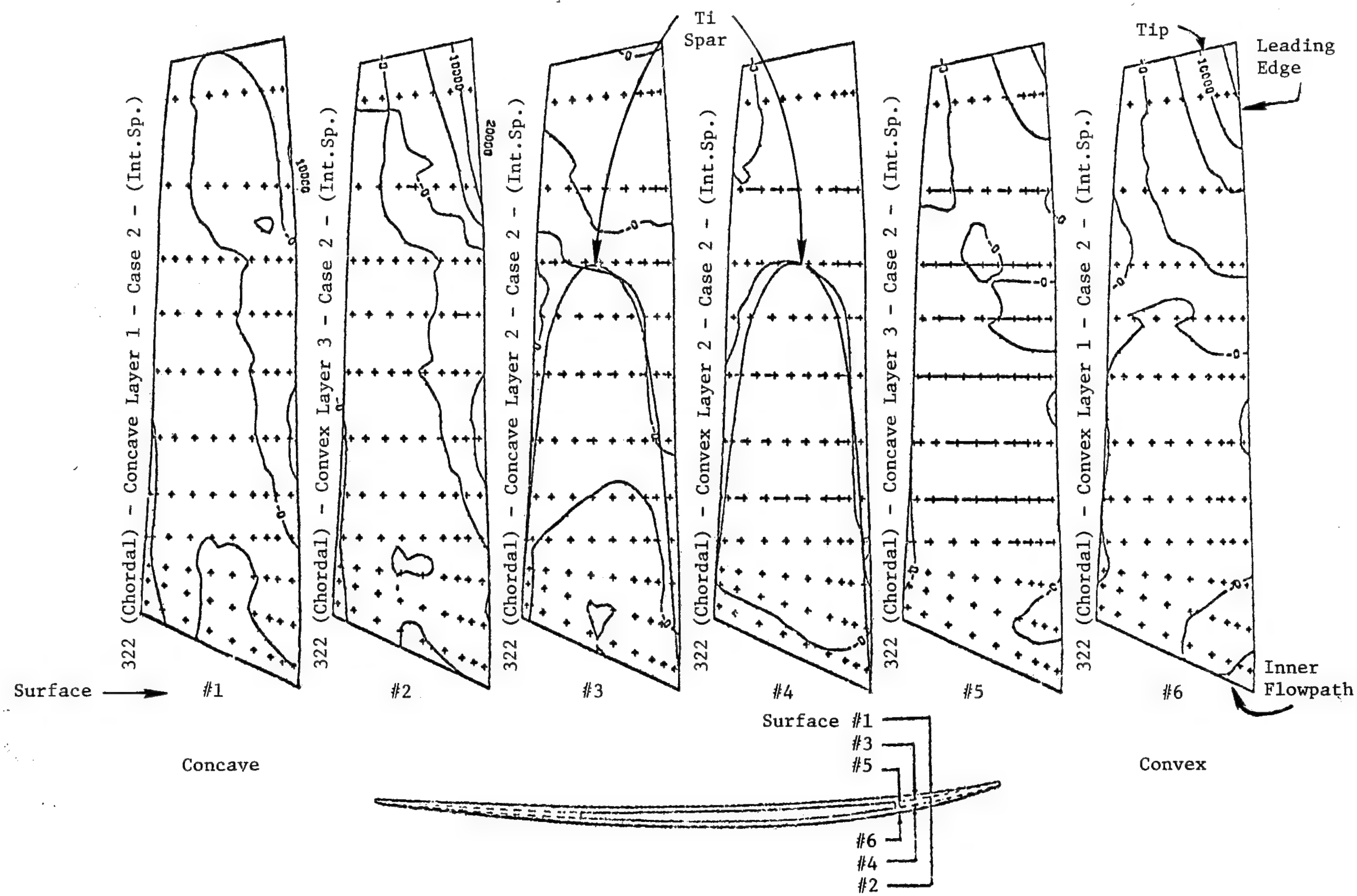


Figure 16. Internal Spar Blade TAMP Chordal Stress (psi), 4080 rpm.

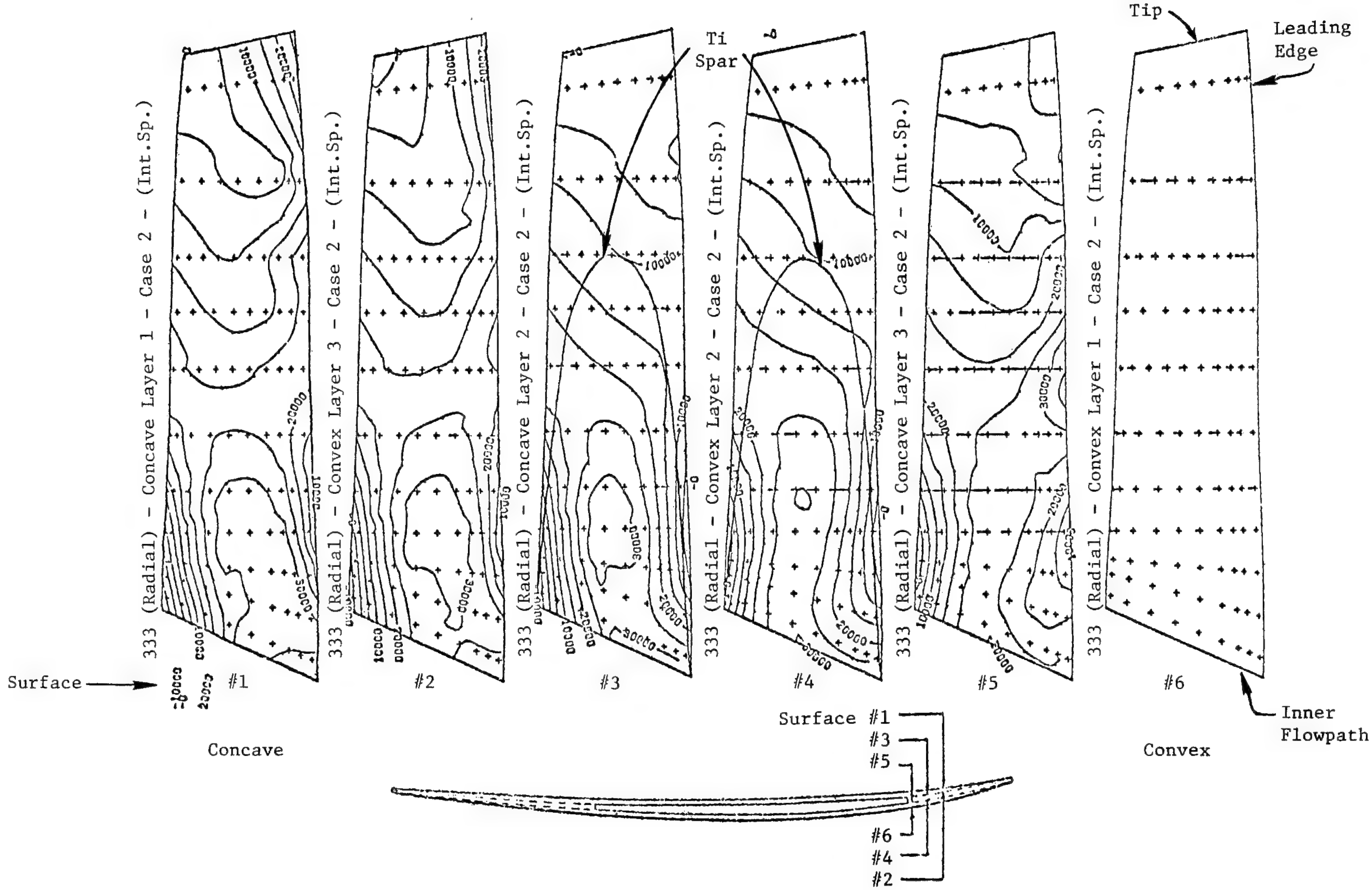


Figure 17. Internal Spar Blade TAMP Radial Stress (psi), 4080 rpm.

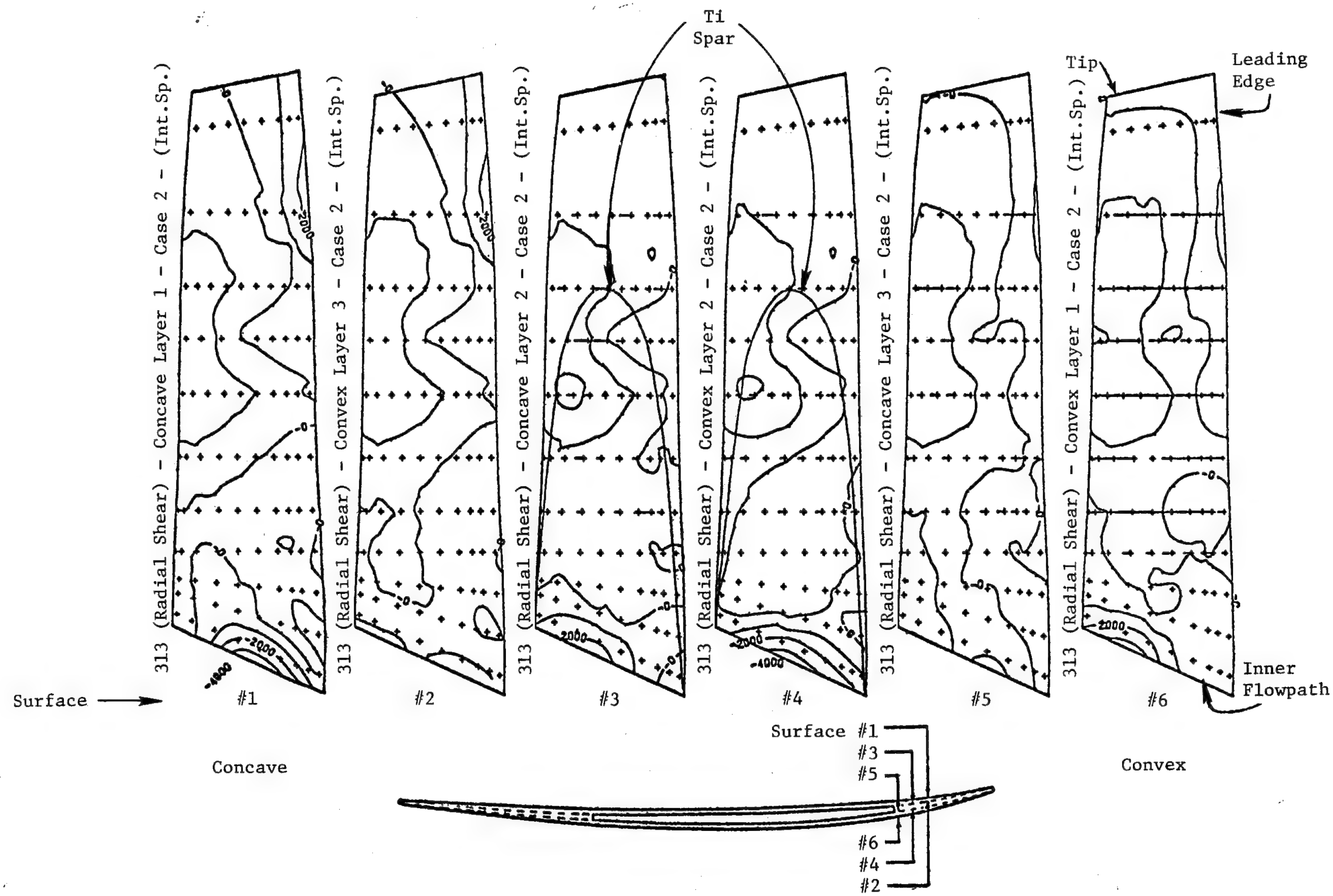


Figure 18. Internal Spar Blade TAMP Radial Shear Stress (psi), 4080 rpm.

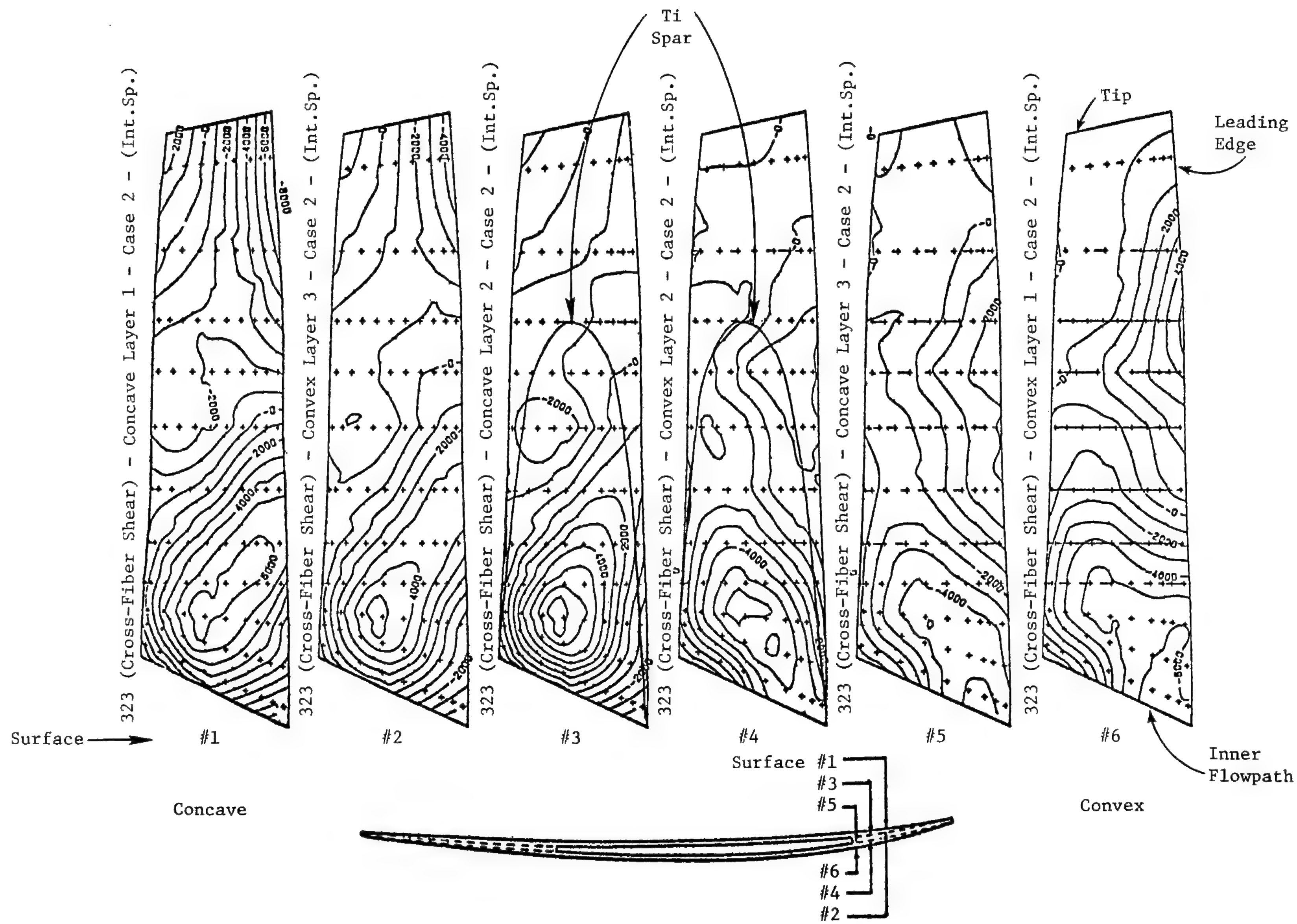


Figure 19. Internal Spar Blade TAMP Cross-Fiber Shear Stress (psi), 4080 rpm.

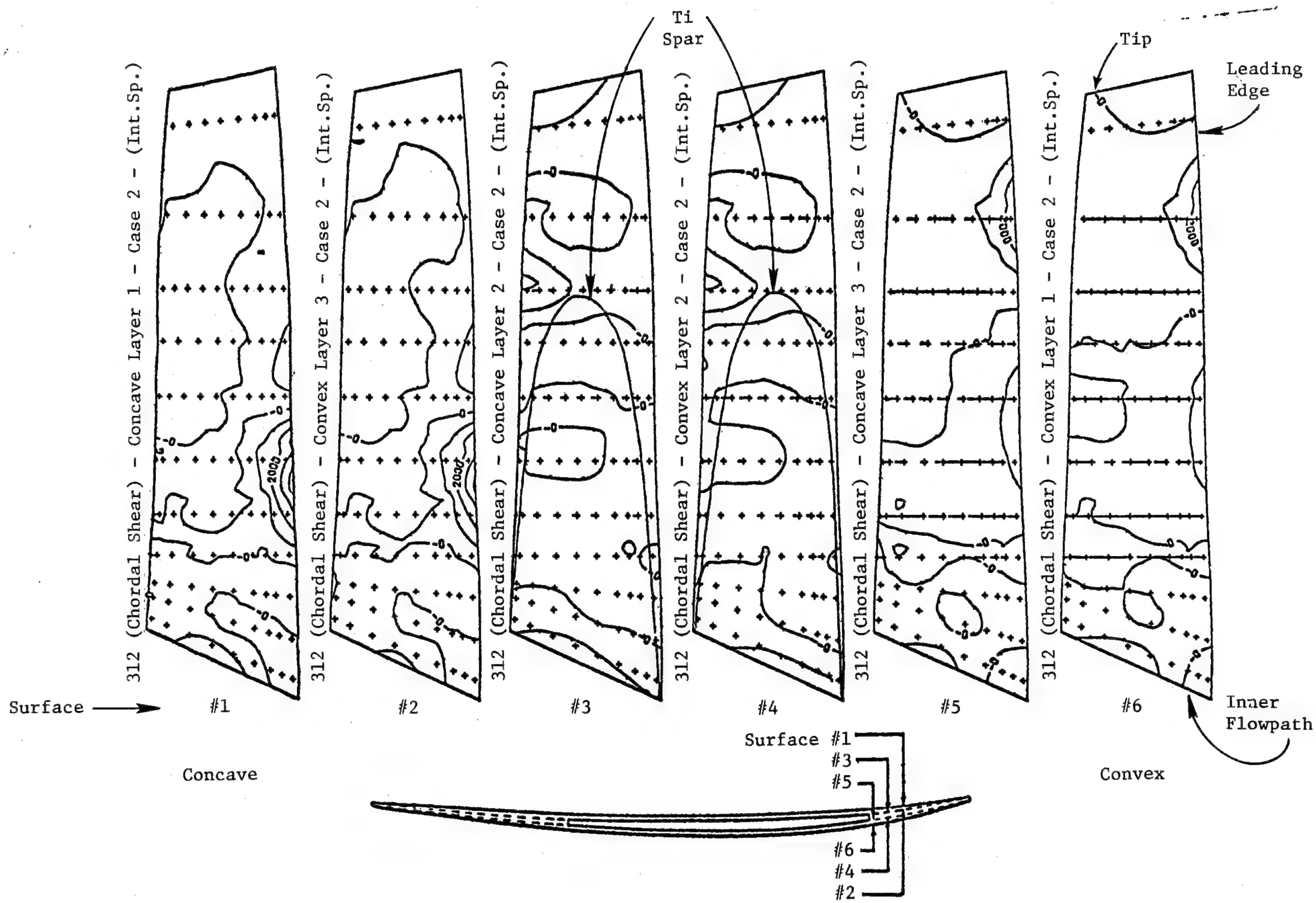


Figure 20. Internal Spar Blade TAMP Chordal Shear Stress (psi), 4080 rpm.

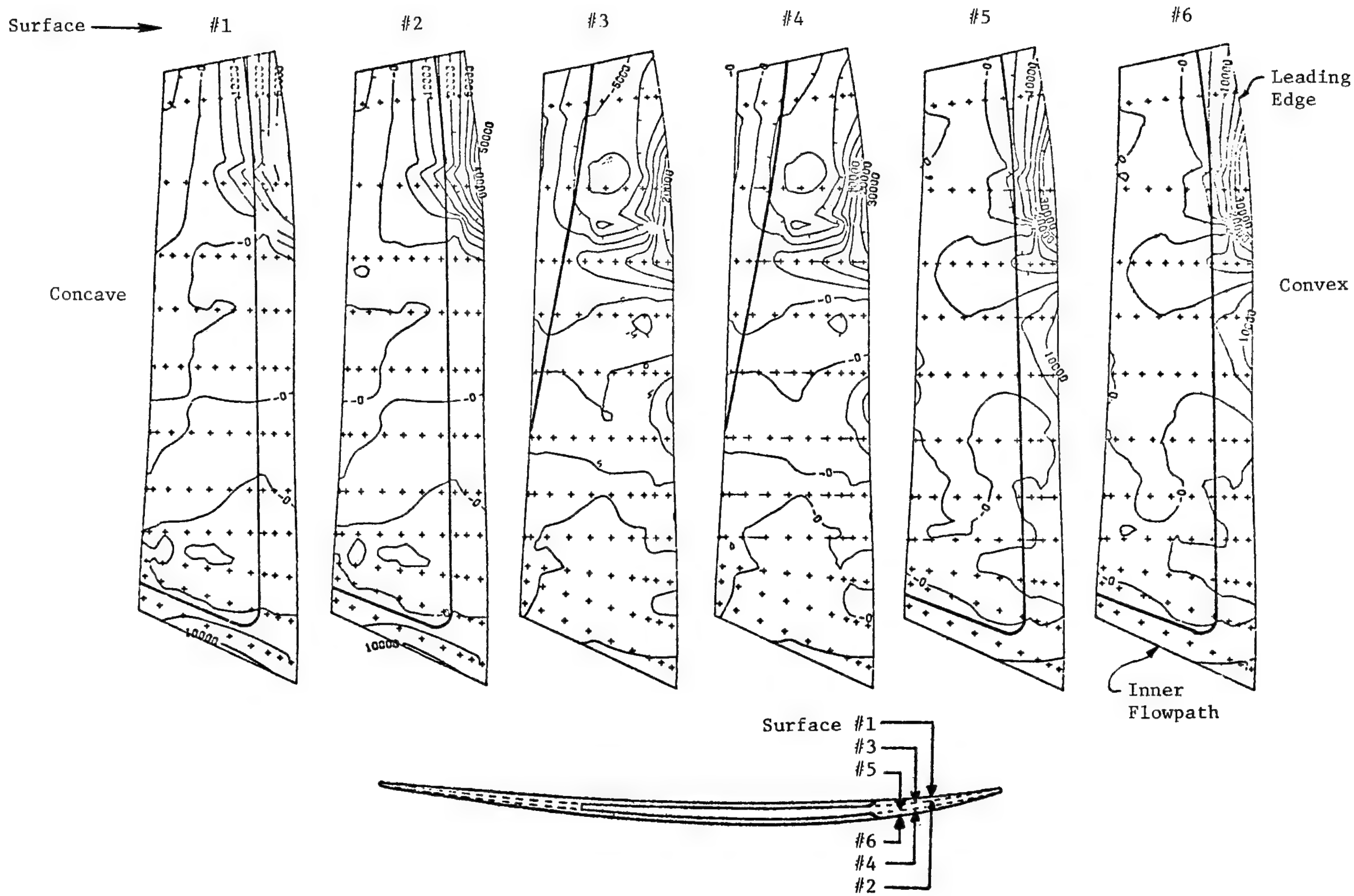


Figure 21. TiCom Blade TAMP Flatwise Tensile Stress (psi), 4080 rpm.

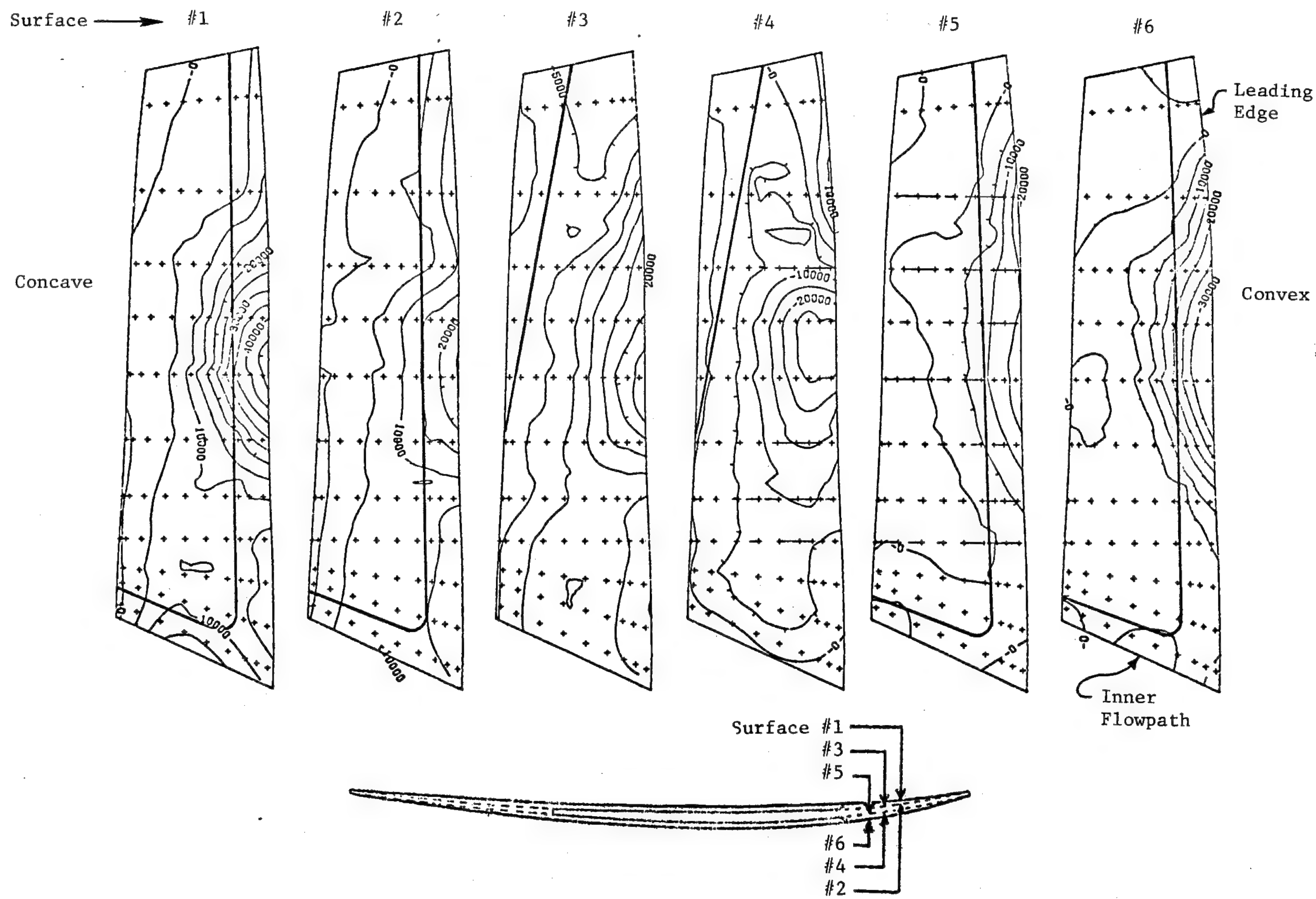


Figure 22. TiCom Blade TAMP Chordal Tensile Stress (psi), 4080 rpm.

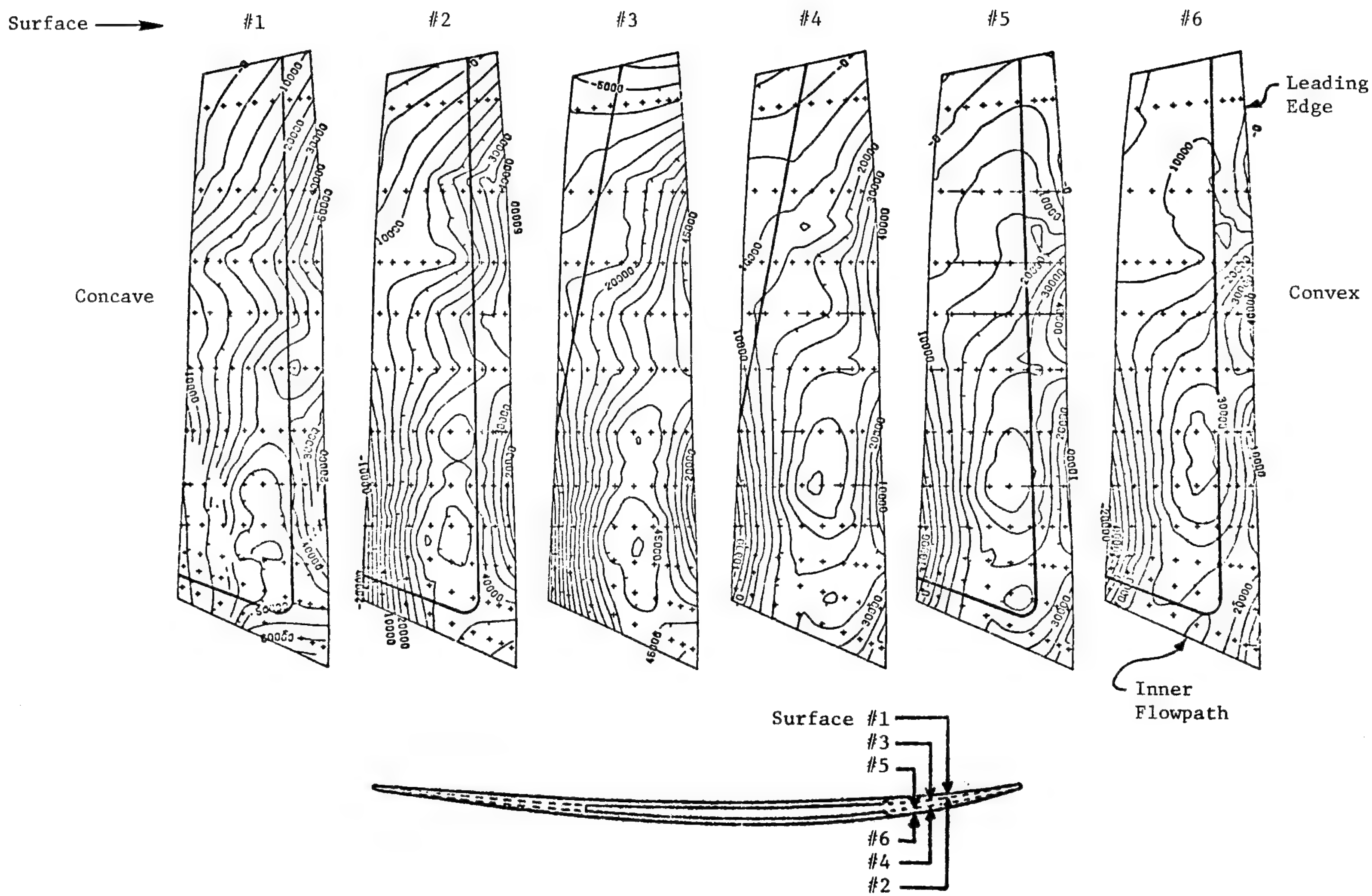


Figure 23. TiCom Blade TAMP Radial Tensile Stress (psi), 4080 rpm.

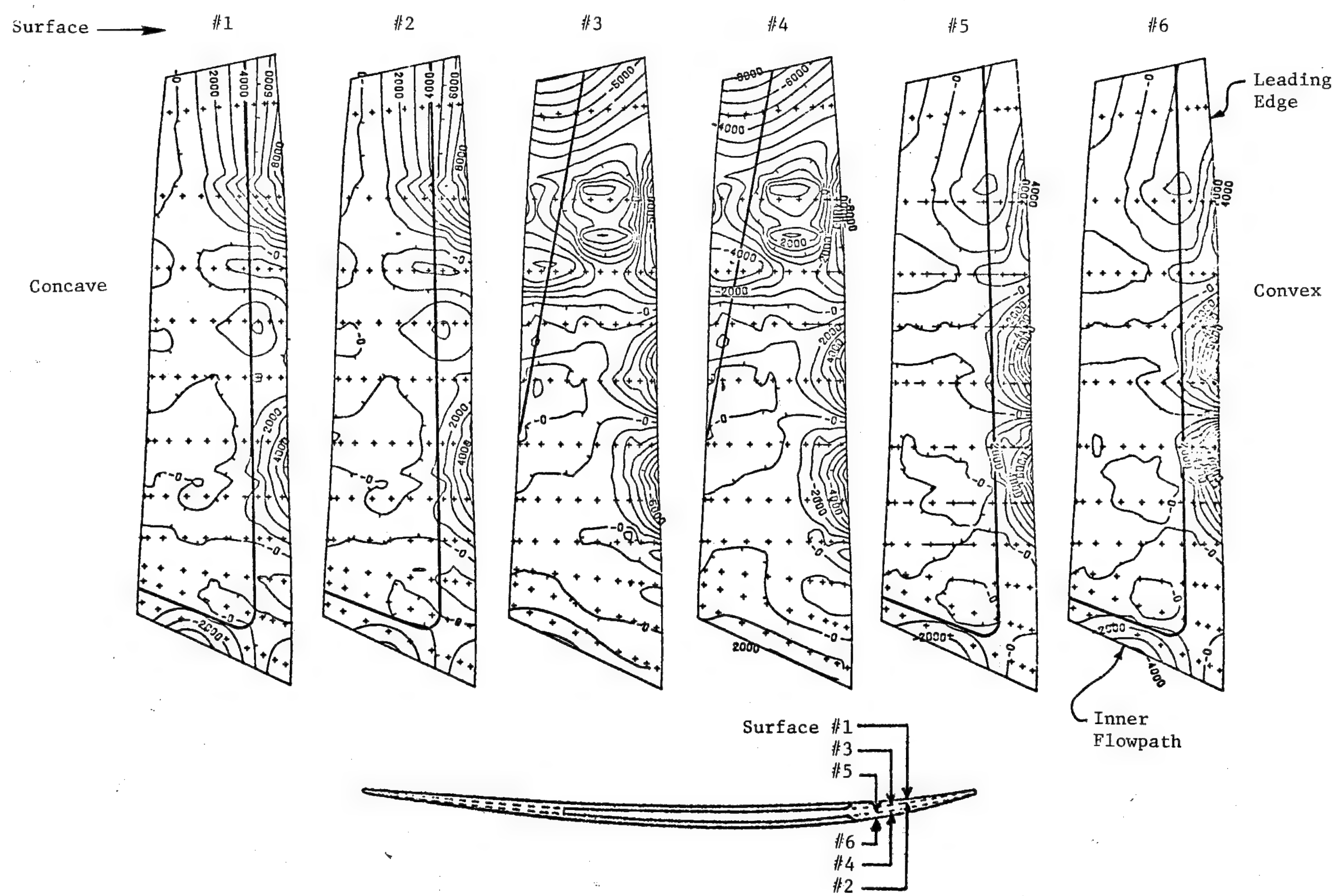


Figure 24. TiCom Blade TAMP Chordal Shear Stress (psi), 4080 rpm.

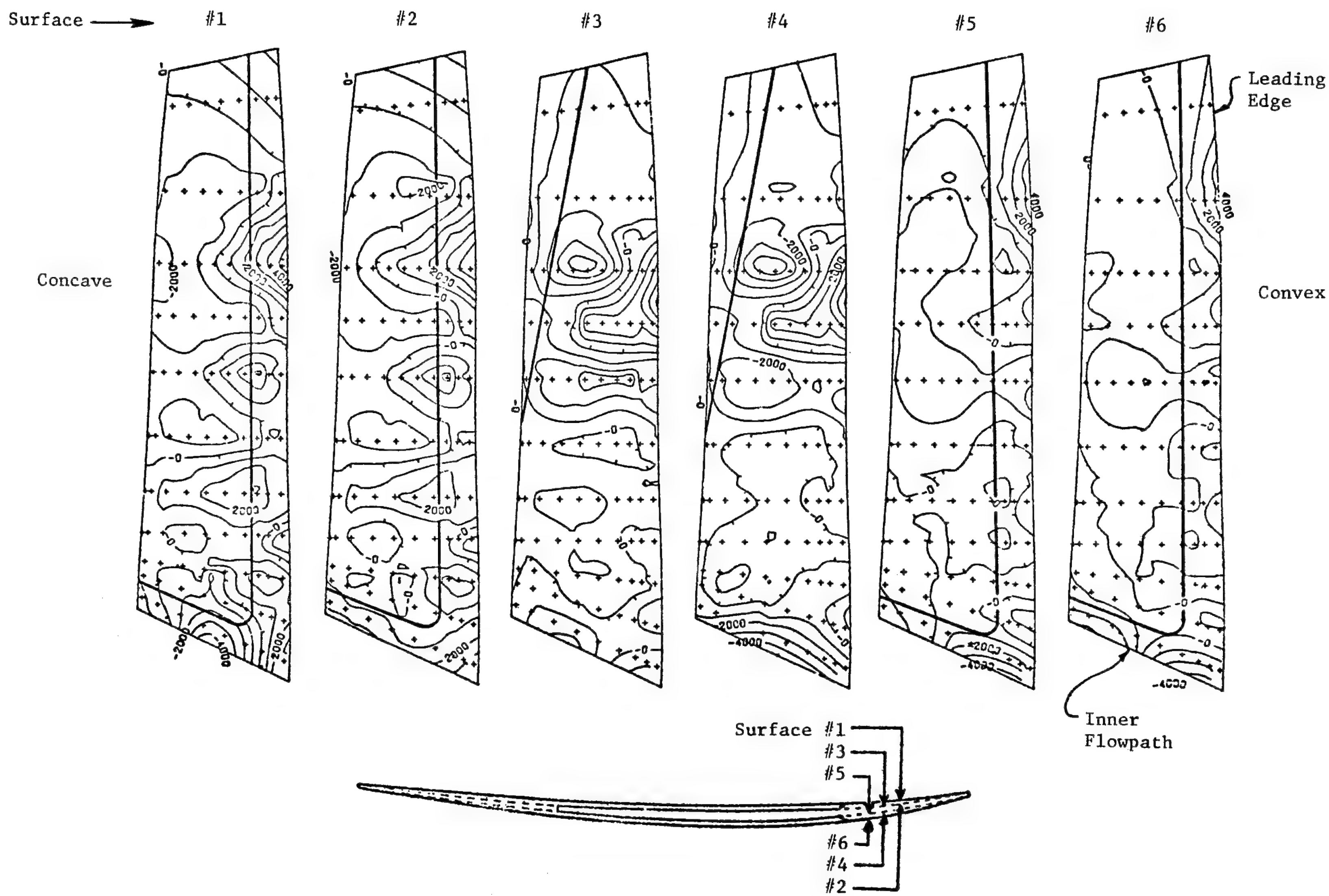


Figure 25. TiCom Blade TAMP Radial Shear Stress (psi), 4080 rpm.

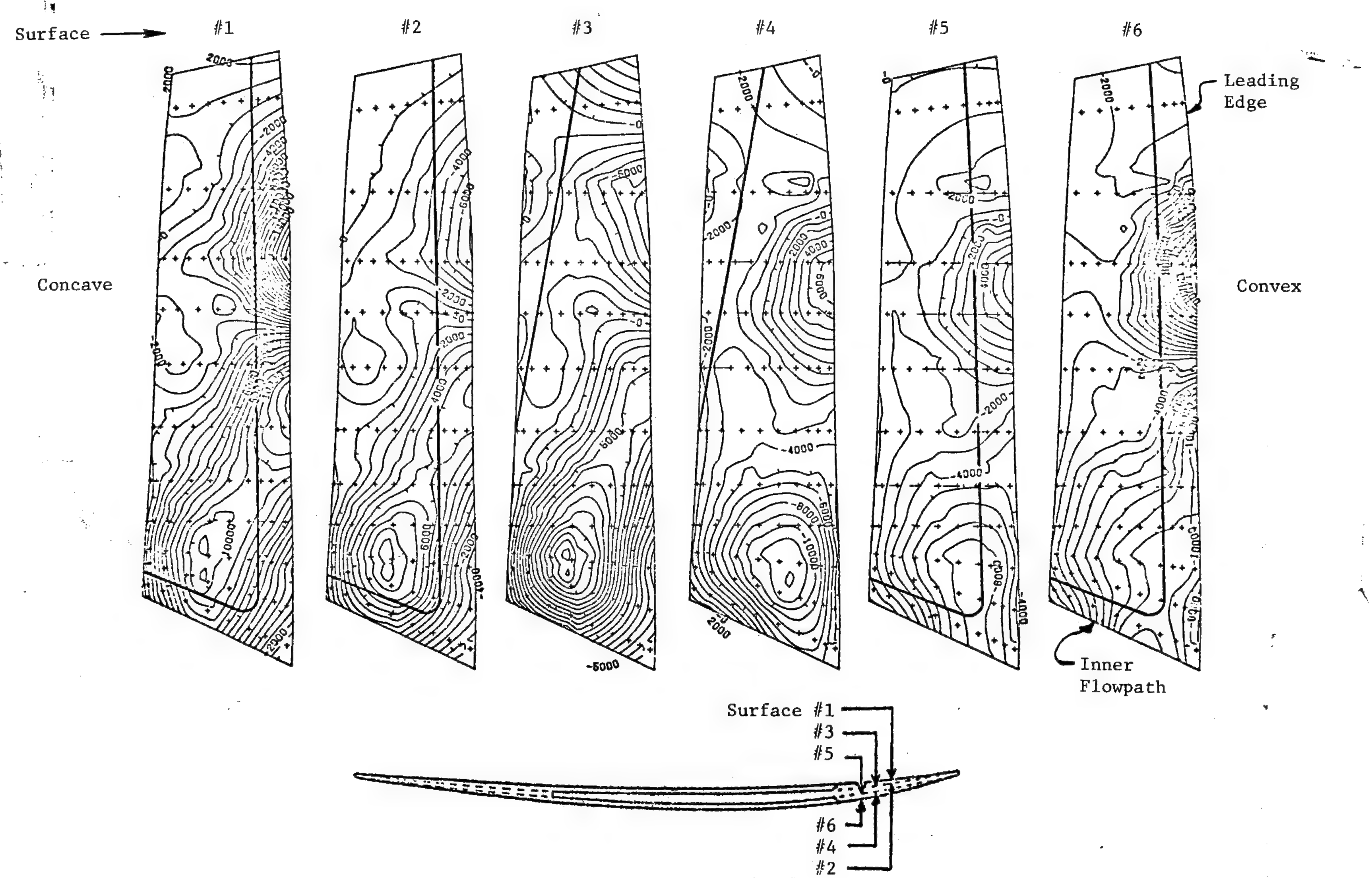
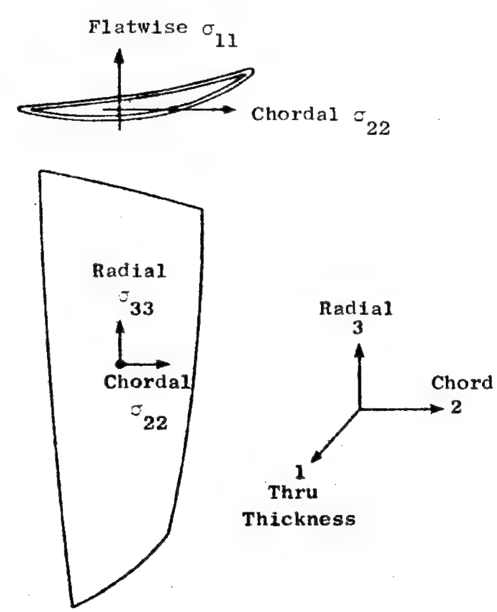


Figure 26. TiCom Blade TAMP Cross-Fiber Shear Stress (psi), 4080 rpm.

Table V. Summary of Peak Stresses for Superhybrid Composite Blades.

(4080 rpm)

	TiCore Blades			TiCom Blades*			
						Design Allowables	
	Stress	Location	Design Allowables	Stress	Location	Superhybrid Material	Titanium Material
Flatwise Tensile Stress σ_{11} - ksi (10^6 n/m^2)	1.0 (6.894)	LE 40% Span	3.0 (20.68)	10.0 (68.95)	Root Midchord Region	3.0 (20.68)	90** (620.53)
Chordal Tensile Stress σ_{22} - ksi (10^6 n/m^2)	5.0 (34.47)	LE 40% Span	22.0 (151.68)	40.0 (275.79)	LE 50% Span	22.0 (151.68)	90** (620.53)
Radial Tensile Stress σ_{33} - ksi (10^6 n/m^2)	35.0 (241.32)	Root LE Region	70.0 (482.63)	65.0 (448.16)	LE Root Region	70.0 (482.63)	90** (620.53)
Chordal Shear Stress τ_{12} - ksi (10^6 n/m^2)	0.5 (3.45)	LE 40% Span	5.0 (34.47)	8.0 (55.16)	LE 40% Span	5.0 (34.47)	50** (344.74)
Cross-Fiber Shear Stress τ_{23} - ksi (10^6 n/m^2)	5.0 (34.47)	Midchord 20% Span	17.0 (117.21)	13.0 (89.63)	LE 40% Span	17.0 (117.21)	50** (344.74)
Radial Shear Stress τ_{13} - ksi (10^6 n/m^2)	4.0 (27.58)	Midchord Root Region	8.0 (55.16)	4.0 (27.58)	Midchord Root Region	8.0 (55.16)	50** (344.74)



* Stresses in the tip region of the blade were found to be unrealistic due to modeling problems associated with very thin elements. Therefore, these stresses have been omitted from this summary.

** Controlling allowable.

show that blade stresses are well within the superhybrid material strengths for the TiCore and TiCom blades. The controlling stresses for the TiCore blade were generally in the superhybrid material; those for the TiCom blade, in the titanium spar material. The stresses in the TiCom blade were considerably higher than those of the TiCore blade.

The higher stresses in the leading edge regions of the TiCom blade are believed to be the result of modeling problems associated with the thin solid-titanium leading edge, and are believed to be unrealistic levels. Since the stresses were within the material allowable limits, no attempt was made to refine the model.

3.3.4 Frequency and Weight Analysis Results

In addition to steady-state stresses, the finite-element analysis is also capable of providing frequencies and mode shapes of composite blades in the cantilever fixed-end condition. Table VI summarizes the first three frequencies for the TiCore and TiCom superhybrid blades at design speed and compares them with those of the titanium midspan shrouded blade. The data indicate that the blade frequencies for both superhybrid blades are equivalent but considerably below the shrouded metal blade. A design change would thus be required, including a change in number of blades per stage, to provide an aeromechanically acceptable design. Also shown in Table VI is the weight advantage of each of the superhybrid blade designs; the TiCore saves about 17%, the TiCom about 15%.

Table VI. Blade Frequencies at 4080 rpm.

	Frequency, Hz		
	Titanium Midspan Supported	Superhybrid Cantilevered	
		TiCore	TiCom
1st Frequency (Hz)	260	115	113
2nd Frequency (Hz)	500	165	163
3rd Frequency (Hz)	450	250	248
Weight*, lb (kg)	Base	-1.9 (-0.862)	-1.7 (-0.771)

*Based on TAMP results.

4.0 BLADE FABRICATION MANUFACTURING PROCESS

4.1 GENERAL DESCRIPTION

The basic manufacturing process employed in producing the required blades is shown diagrammatically in Figure 27 and is described in the following paragraphs.

4.2 MATERIAL SELECTION

PR288/AS(80)/S(20) - Graphite - Glass Epoxy Hybrid Prepreg

The material was procured against GE Specification 4013163-485 - Unidirectional Hybrid Fiber Preimpregnated Tape or Wide Goods. The Quality Control Data Summary Sheet is shown in Table VII. When the material was released, it bore one deviation from the specification: the fiber weight per unit area in the S-glass portion of the prepreg was determined to be 3.97 grams/ft^2 (42.73 gram/m^2), whereas the specification limit was 3.5 grams/ft^2 $\pm$ 0.3 gram/ft^2 (37.67 g/m^2 + 3.22 g/m^2). The vendor quality control data indicated that the fiber weight was within limits at 3.7 grams/ft^2 (39.82 g/m^2).

Titanium 6Al/4V Sheet

The titanium sheet was procured against AMS 4911D specification; 30 sheets were received, each measuring 18 by 30 inches and having a thickness of 0.016 inch (0.457 x 0.762 x 4.064 x 10^{-4} m). The hydrogen content of the sheets, as received, varied from 0.004 to 0.009% (40 ppm to 90 ppm), and was further reduced to 0.0012 to 0.0021% (12 ppm to 21 ppm) by vacuum heat treating at the General Electric Company for 8 hours at 1200 to 1250° F (649 to 677° C) and 5 x 10^{-4} Torr, 0.0666 n/m^2 (1/2 micron), pressure.

Boron/Aluminum Sheet

Twenty-five boron/aluminum sheets were purchased from Avco Corporation. The sheets measured 33 x 27 inches and varied in thickness from 0.0072 to 0.0078 inch. The sheets were prepared from 0.0056-inch-diameter boron filament (GE specification 2013155-588 Class B) and commercial grade 1100 aluminum foil matrix. Parameters for preparation of bonded monotape sheets were 960° F (516° C) at 4 ksi (27.57 x 10^6 n/m^2) pressure. Permissible defect criteria and quality assurance provisions were controlled by GE specification 4013155-235. The volume percent of boron filament was maintained at 46 to 47% (specification requirement 47.5 $\pm$ 2.5%). Filament tensile strengths determined according to GE specification 4013155-237 (Tensile Testing of Boron Filament) ranged from 460 ksi (3.17 x 10^9 n/m^2) to 540 ksi (3.72 x 10^9 n/m^2) against specification requirement of 450 ksi (3.10 x 10^9 n/m^2) minimum.

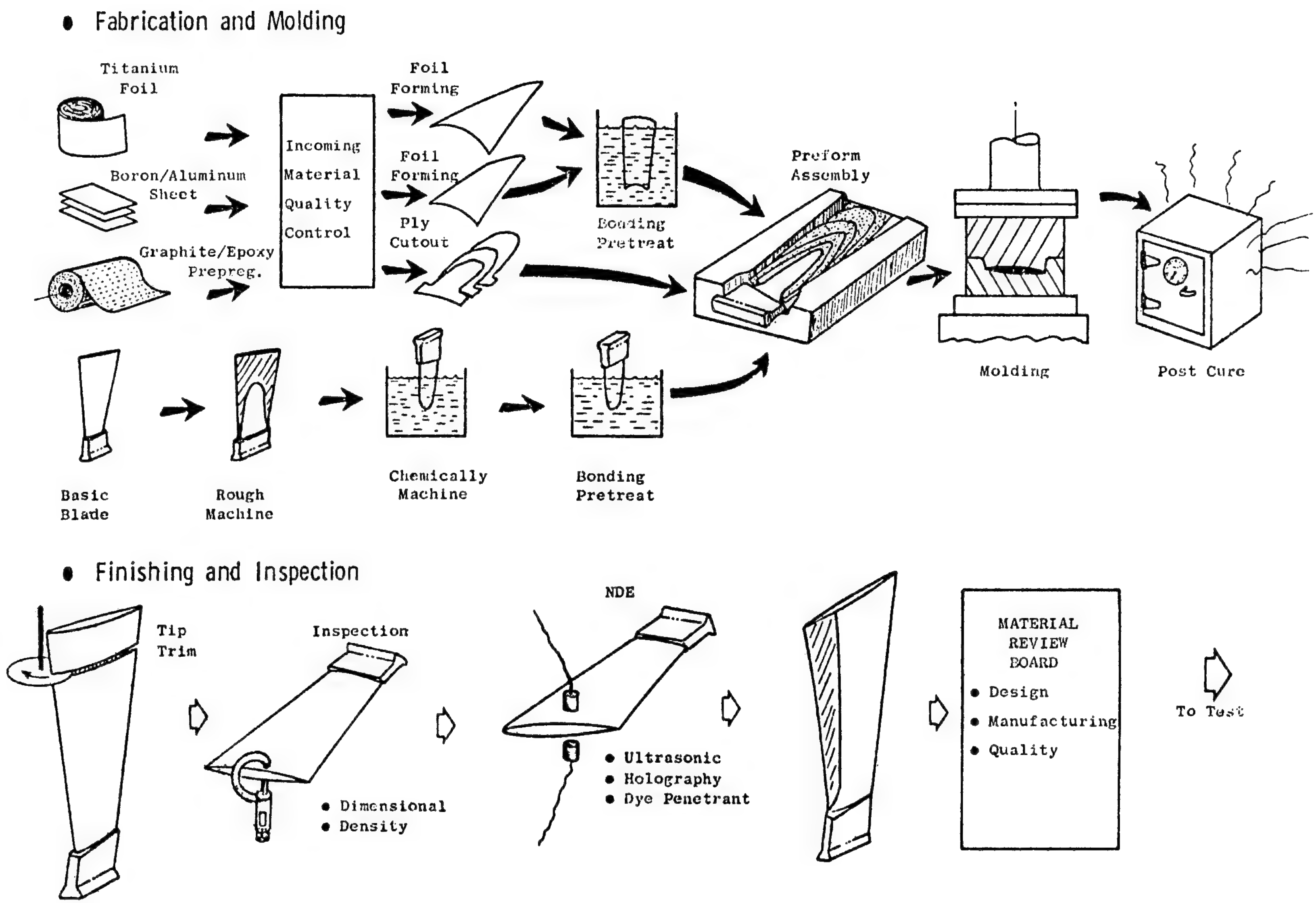


Figure 27. Basic Superhybrid Blade Manufacturing Process.

Table VII. Quality Control Data Summary - Hybrid Prepreg.
(Specification 4013163-485) Cl A

Addendum ________

Prepreg Lot No. 695 | Date Received 11/18/77
Prepreg Type PR288/80AS/20S | Expiration Date 05/18/78
Quantity 100 lb, 2100 ft | Resin Batch No. 451 and 500
Fiber Batch No. AS - Hercules Lot 44-4

A. Graphite Data	Vendor	MPTL	Spec.	Accept	Reject
Batch No.	44-4	-			
Tensile Str., ksi, Avg	444	-	410 min.	x	
Tensile Mod., msi, Avg	33.5	-	29 - 34	x	
Density, gm/cc, Avg	1.787	-	1.785-1.827	x	
B. Prepreg Data					
Graphite, gm/ft^2, Avg	10.3	10.00	10.2 ± 0.4*	x	
Individ. Specimens***	3/3	3/4	2/3	x	
Sec. Fiber, gm/ft^2, Avg	3.7	3.97	3.5 ± 0.3**	x	
Individ. Specimens***	3/3	2/3	2/3		x
Total Fiber wt, gm/ft^2, Avg	14.0	13.97	13.7 ± 0.4	x	
Individ. Specimens	6/6	5/8	2/3	x	
Resin, gm/ft^2, Avg	7.5	7.09	7.3 ± 0.5	x	
Individ. Specimens***	3/3	3/3	2/3	x	
Vols., % wt., Avg	0.3	0.16	2% max	x	
Individ. Specimens***	3/3	3/3	2/3	x	
Gel Time, min. @ 230° F	68	52	40 min	x	
Flow, % @ 230° F	--	--	3 - 7		
Visual Discrepancies					
C. Laminate Data Panel No.					
Roll No.'s	9-16				
Gel Time in Die, min.		--			
Thickness, in.	--	0.079	0.080 ± 0.002	x	
Flex. Str. @ R.T., ksi	200	216	195	x	
@ 250° F, ksi	175	221	170	x	
Flex. Mod. @ R.T., msi	14.6	15.91	14.0	x	
@ 250° F, msi	13.3	15.8	13.0	x	
SBS Str. @ R.T., ksi	16.8	16.34	14.0	x	
@ 250° F, ksi	10.2	10.26	8.5	x	
Fiber Volume, %	58.99	61.6	48/12 (60 ± 2)	x	
Resin Content, % wt.	30.91	29.43	Report	x	
Voids, %	0.32	-0.5	2% max		
Density, gm/cc	1.67	1.68	Report	x	

D. Material Disposition

Accept for All Usage ________ Reject ________ and (a) Return to Vendor ________ or (b) Available for Limited Use Only ________.

Q.C. Eng. ________ Date: 3/8/78

*Graphite wt. = 5.66 x Sp. Gr. of fiber
**Sec. Fiber wt. = 1.42 x Sp. Gr. of fiber
***No. of specimens in Spec./No. of specimens tested

4.3 FOIL FORMING TECHNIQUES

The initial method proposed for the forming of the outer airfoil titanium foil ply was a hot isostatic creep forming process [Cost Reduction in Static parts by creep isostatic Pressing (CRISP)]. Since the CRISP process was not fully developed and potential tearing of the 0.016-inch (4.06×10^{-4} m) sheet was predicted - especially with the deep draws of the proposed ceramic dies - an alternative process was developed in conjunction with Jet Die Company, Lansing, Michigan.

The final technique developed entailed the fabrication of matched Meehanite cast steel tooling. The 0.016-inch (4.06×10^{-4} m) titanium sheet stock blanks were partially creep formed into the female die by heating to a super-plastic condition [1600 to 1700° F (871 to 926° C)]. An inert gas was used to prevent oxidation resistance. The preformed blanks were then finally coined in the Meehanite matched tooling at a temperature of 1250 to 1350° F (677 to 932° C). The technique enabled highly accurate formed foils to be produced with fairly uniform material thickness control and with minimum springback.

The same tooling was also utilized in the forming of the boron/aluminum foils. Two slave sheets of aluminum were press-formed in the die set. The boron/aluminum developed ply sheet was preformed almost to size and with the correct 15° ply orientation. The flat ply was then sandwiched between the two aluminum preformed slave sheets and placed into the matched die set. Pressure was slowly applied to creep-form the boron/aluminum foil to the compound curvature of the die profile at a temperature of 875° F (468° C).

This process yielded consistent preformed plies of titanium and boron/aluminum for all blades in the program. A typical set of foils is shown in Figure 28 for the initial TiCom blade.

4.4 METALLIC FOILS PREBONDING TREATMENT

The initial AF163 high-peel-strength adhesive selected for bonding the outer ply of titanium to boron/aluminum plies and the boron/aluminum to the polymeric composite core (PR288/AS/S) in addition to the core-to-titanium spar created an excessive "melon seed" reaction which extruded the composite core material during the cocuring molding process. The phenomenon was demonstrated in test specimen form showing simulated core material extrusion. The problem was resolved by using a low-flow version of the AF163 adhesive, designated AF3185, at the critical bonding interfaces which were the composite core to spar and the composite core to the boron/aluminum plies. The low-flow adhesive reduced the slip characteristics and increased the gripping force on the core material at these critical surfaces. The revised procedures were demonstrated in these test specimens prior to the successful inclusion into the superhybrid blade cocuring molding process.

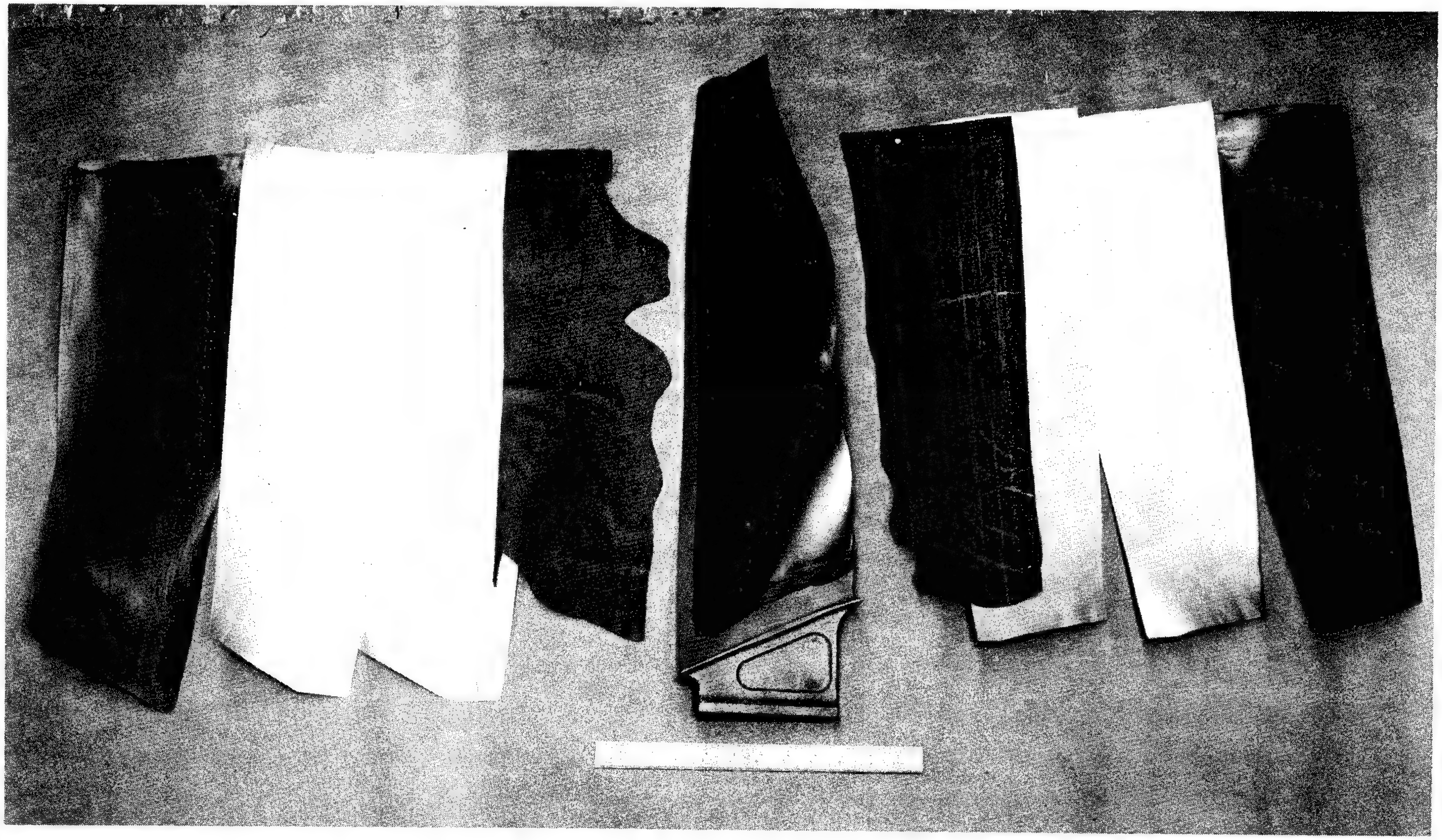


Figure 28. Preformed Metalic and Composite Plies for TiCom Blade.

This procedure was as follows:

- Degrease using methal ethyl ketone (MEK).
- Grit-blast the bonding surfaces using No. 150 aluminum oxide grit at 20 psig (137,895 n/m^2).
- Treat surfaces with PASA-JEL 107M (GE specification A15D3-B1) by immersion; water rinse.
- Prime surfaces [0.1 to 0.3 mil (2.54×10^{-6} to 7.62×10^{-6} m)] with 3M Company XA-3950; air dry and seal.
- Store in cold storage at 0° F (17.78° C) until ready for use.

This same procedure was used in the pretreatment of B/Al plies.

4.5 MANUFACTURE OF TITANIUM SPAR

Four spars of each of the two designs were produced using CF6 shrouded titanium fan blades. The initial two spars were produced in-house using conventional machining techniques, including removal of the midspan shrouds, rough machining to required profile, and finish by hand-benching and polishing to guillotine gage templets.

The remaining three spars of each design were chemically etched by Chem-Tronics, El Cajon, California. After their manufacture, these spars were heat-treated to eliminate any hydrogen retention caused by chemical etching.

Typical spars of each design are shown in Figures 29 and 30. The leading-edge spar (Figure 30) is shown after the prebonding primer treatment has been conducted.

4.6 BLADE PREFORMING

4.6.1 Generation of Ply Patterns

Because of the small quantity of blades manufactured and the associated inconsistencies in spar geometry, it was necessary to create a unique set of ply patterns for each blade. This was achieved by accurately locating each spar into the die and then casting around the spar to fill the die cavity, thereby producing a concave and convex shell. Each of these shells was then used to generate the ply patterns by conventional scribing techniques as shown in Figure 31. Typical graphite/glass/epoxy ply patterns and preform assembly are shown in Figures 32 and 33, respectively.

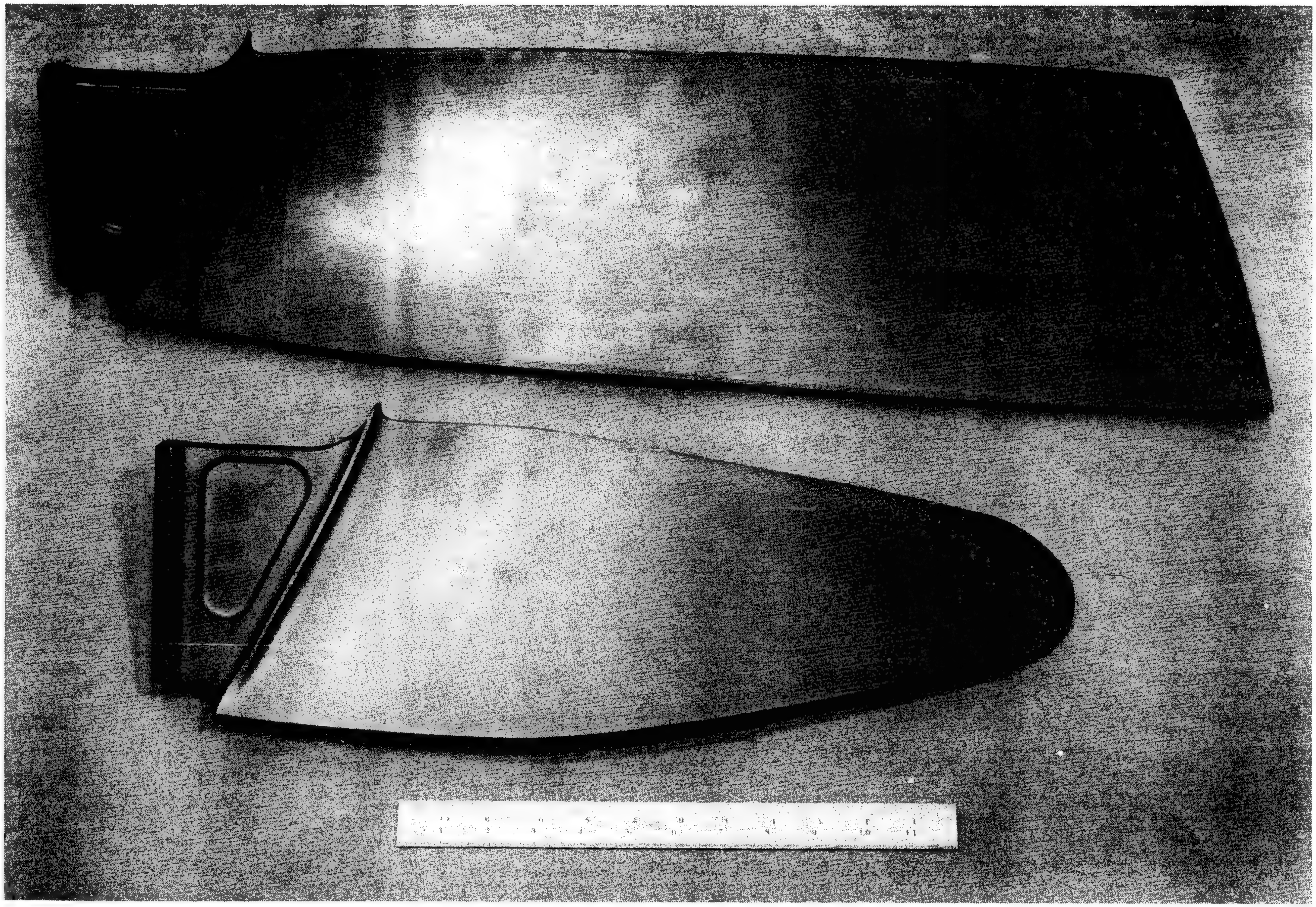


Figure 29. Superhybrid TiCore Blade Shown with Internal Spar.

Figure 30. TiCom Spar Shown After the Prebonding Primer Treatment Has Been Applied.

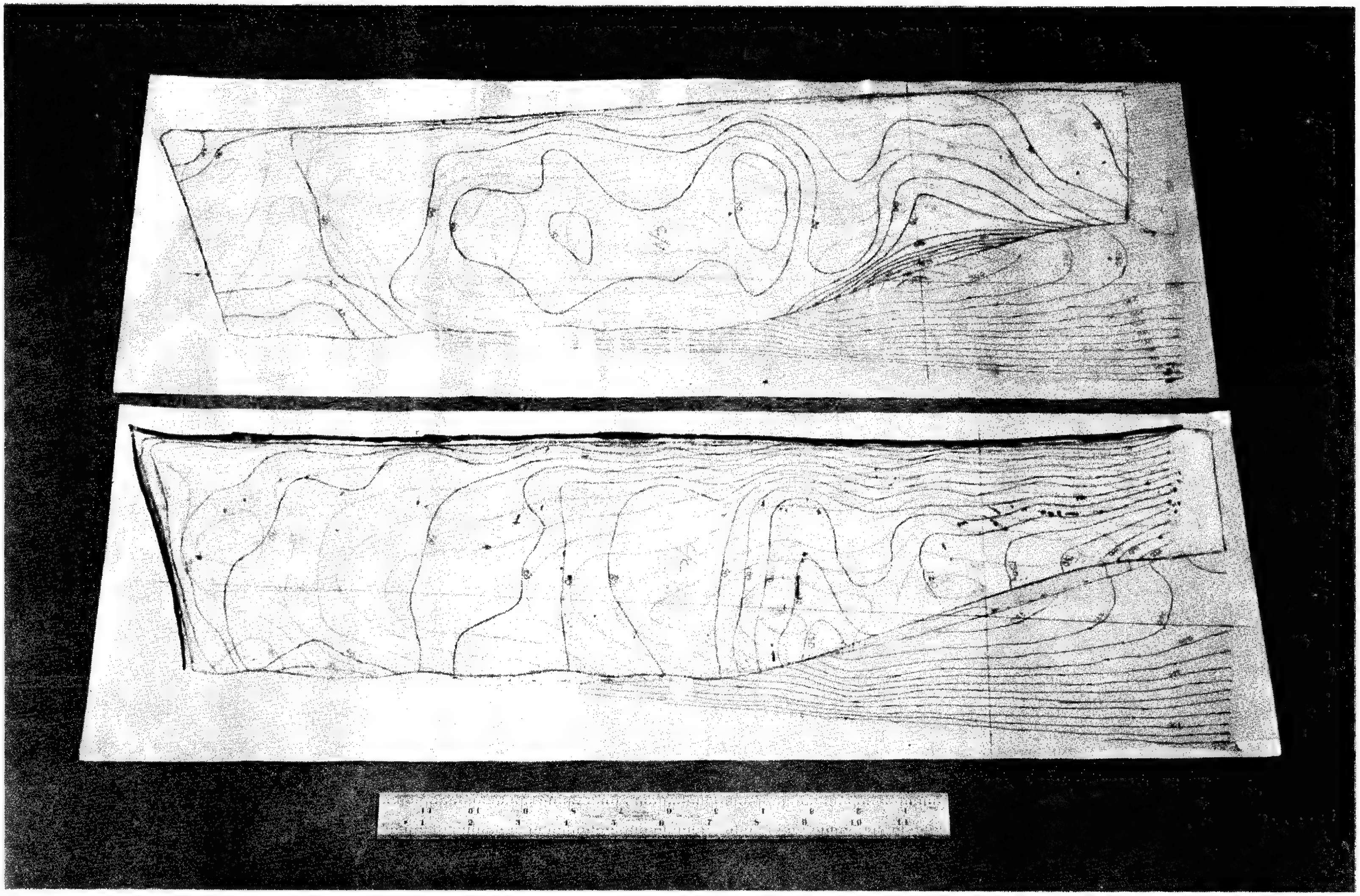


Figure 31. Topography Map of Spar and Shell Superimposed for Superhybrid TiCom Composite Blade.

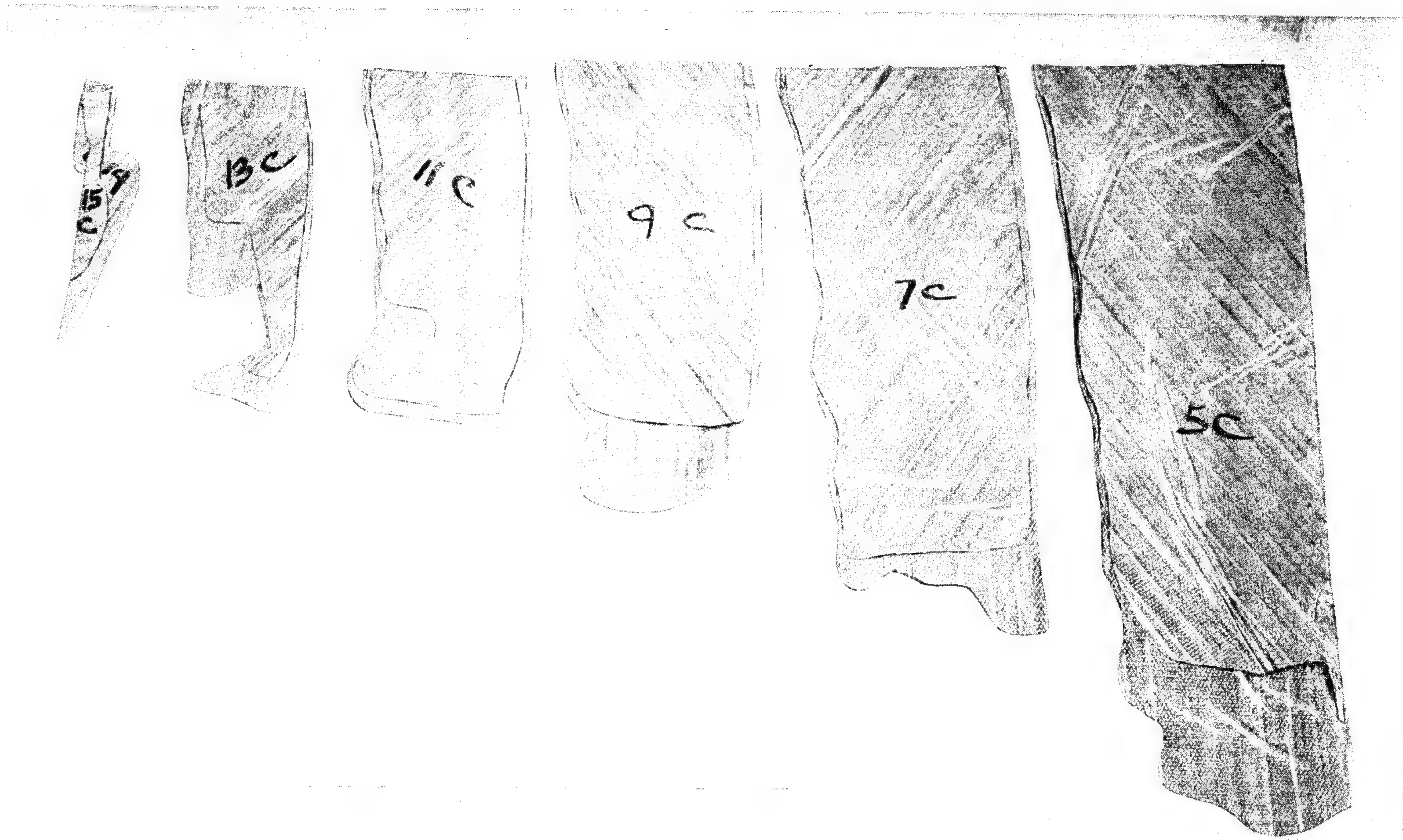


Figure 32. Typical Graphite/Epoxy Ply Patterns for Superhybrid Blade.

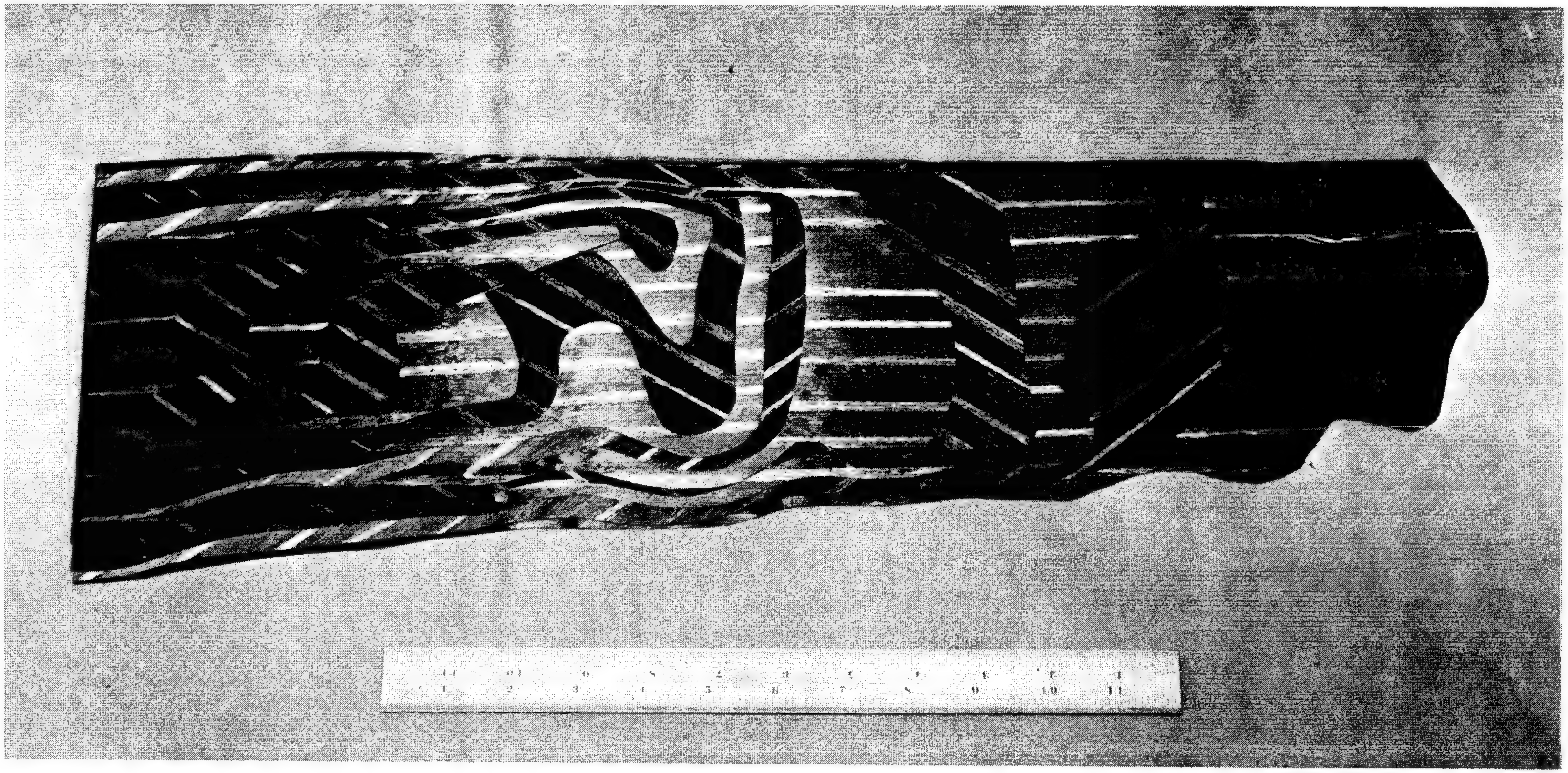


Figure 33. Graphite/Glass/Epoxy Preform Assembly for Superhybrid Blade.

4.6.2 Preform Assembly

The assembly of the various elements of the blade into a final preform was achieved in steps, using the mold tool as an assembly fixture. This procedure was as follows:

- Clean the airfoil surfaces of the mold tool punch. (The mold tool punch is the mold half that produces the convex (C/V) side of the blade.)
- Place the C/V titanium skin in the fixture.
- Plate the C/V boron/aluminum skin over the titanium skin in proper alignment at the leading and trailing edges.
- Place the C/V prepreg preform.
- Position the spar into place matching the platform to the mold tool.
- Place the concave (C/C) prepreg preform over the spar.
- Plate the C/C boron/aluminum skin into the fixture.
- Place the C/C titanium skin into the fixture as the final step.
- Hand press the entire assembly together and remove the preform tool.
- Store in cold storage at 0° F (17.78° C) until ready for molding.

4.7 BLADE FABRICATION

4.7.1 Mold Tool Design

In view of the small quantity of blades produced for this program, the "soft" mold tool technique was employed as opposed to the normal sophisticated steel mold used for quantity production. The basic construction of the mold tool (Figure 34) employs high-temperature-resistant, metallic-fixed, epoxy casting resins. The high loading of aluminum and steel particles improves the compressive strength, thermal stability, and heat conductivity, and results in less shrinkage than the conventional expoxy tooling resins.

The mold tool was produced by casting each half around a master model titanium CF6-50 fan blade which had the midspan shroud machined away. Figure 35 shows a typical prototype blade mold tool.

Prior to removal of the master model, the mold was postcured in excess of the part molding temperature to achieve maximum heat distortion-free material properties.

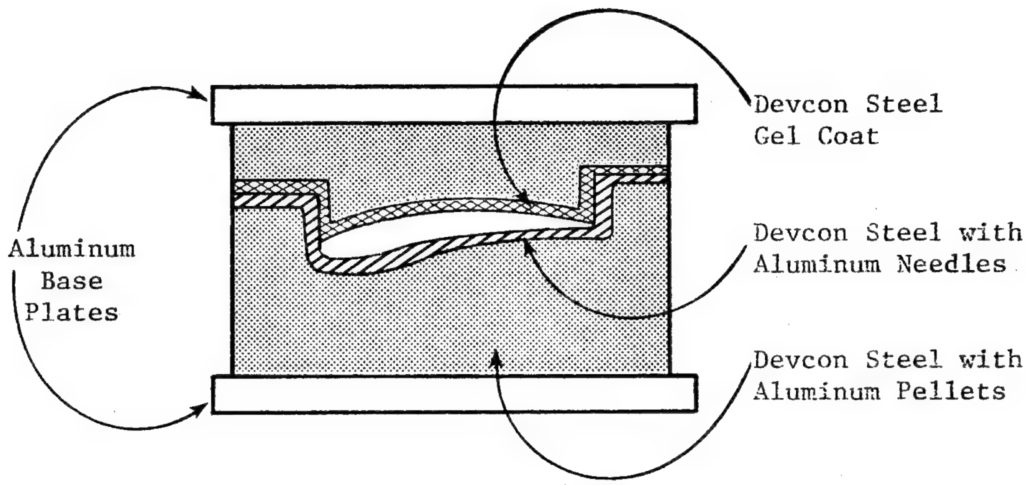


Figure 34. Mold Tool Construction.

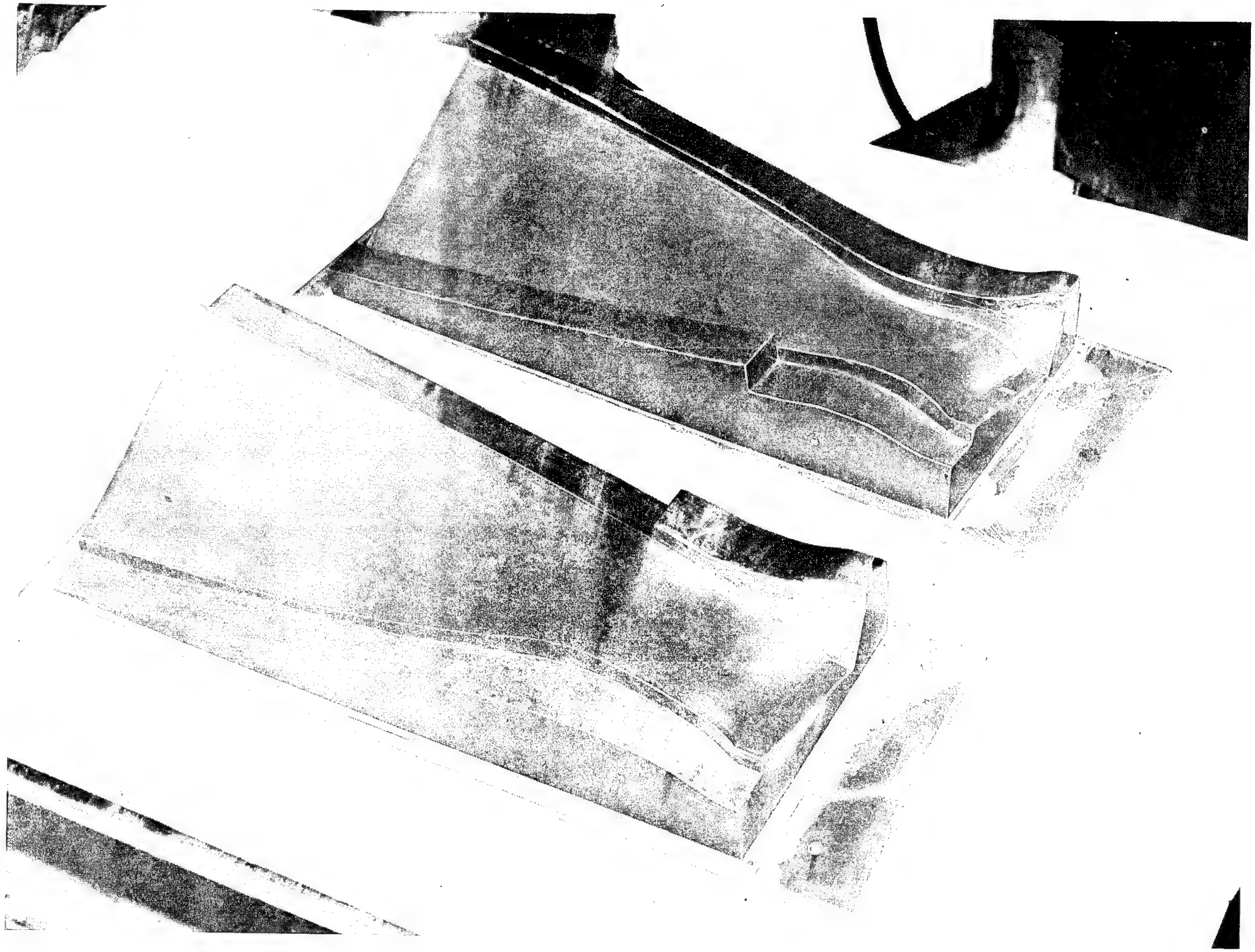


Figure 35. Prototype Blade Mold Tool.

4.7.2 Molding Press

The manufacture of the superhybrid composite blades was performed in a specially designed molding press, shown in Figures 36 and 37. This 300-ton (272.2-ton metric) capacity press embodies many novel features which improve blade manufacturing capability.

The bottom platen indexes out of the press to ease loading of the preform and extraction of the blade molding. Since the mold bottom section is permanently bolted to the indexing heated platen, no mold tool heat loss is experienced. This feature prevents any mismatch between the guide pin and bushings of the die top and bottom sections associated with differential thermal expansion.

The top heated platen, operated by two auxiliary hydraulic rams, hinges down into a vertical position, as shown in Figure 38, exposing the top portion of the mold for the purpose of efficient cleaning and application of release agents. The platen movements and the pressing cycle are fully automatic or, alternatively, can be manually controlled through each sequence. The equipment contains provisions for

1. Variable fast approach speed
2. Variable intermediate slow closing speed
3. Variable dwell cycle
4. Continuously variable slow closing speed down to 0.0005 inch per minute
5. Time curing cycle
6. Water cooling and air purging of the platens

The two 4 x 4 foot (1.22 x 1.22 meter) platens are induction-coil heated with independently programmed heating rate capabilities by means of a Data Trak (Research Incorporated) controller to allow for differential heating of the mold tool. A 12-channel recorder is incorporated to monitor thermocouple temperatures embedded into each platen and in the sections of the mold tool. An additional two-channel recorder continuously monitors molding pressure/load and the critical approach speed over the last 2 inches (3.08 cm) of mold closure. All the press hydraulic movements are electrically sequenced and fully interlocked to prevent any possibility of malfunctioning.

All these unique features are built into the press to improve repeatable process control and semiproductionized methods and to remove the human element associated with hand-operated equipment, thereby improving product quality and reducing part costs by lowering inherent scrap rates.

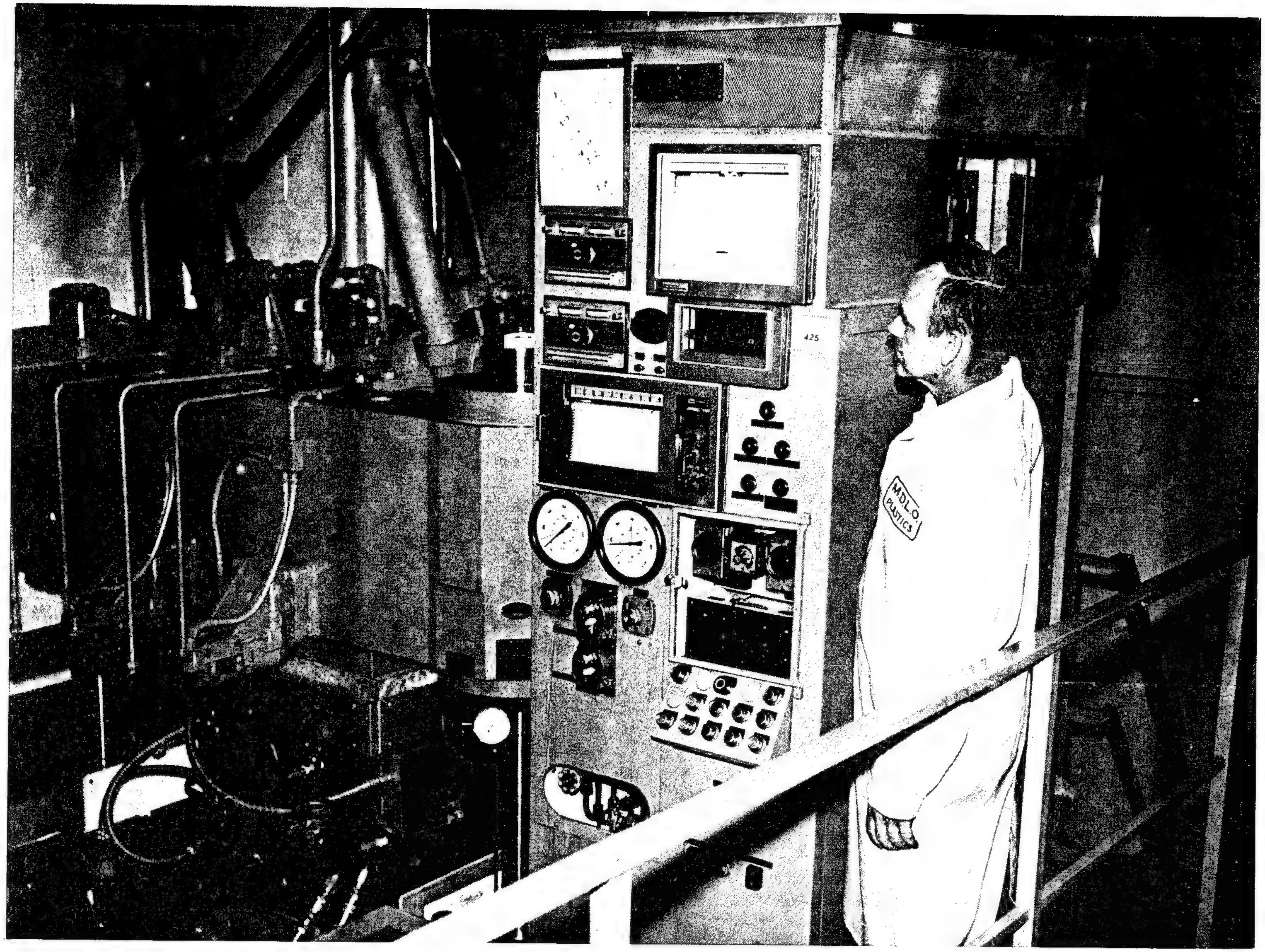


Figure 36. 300-Ton Press, View A.

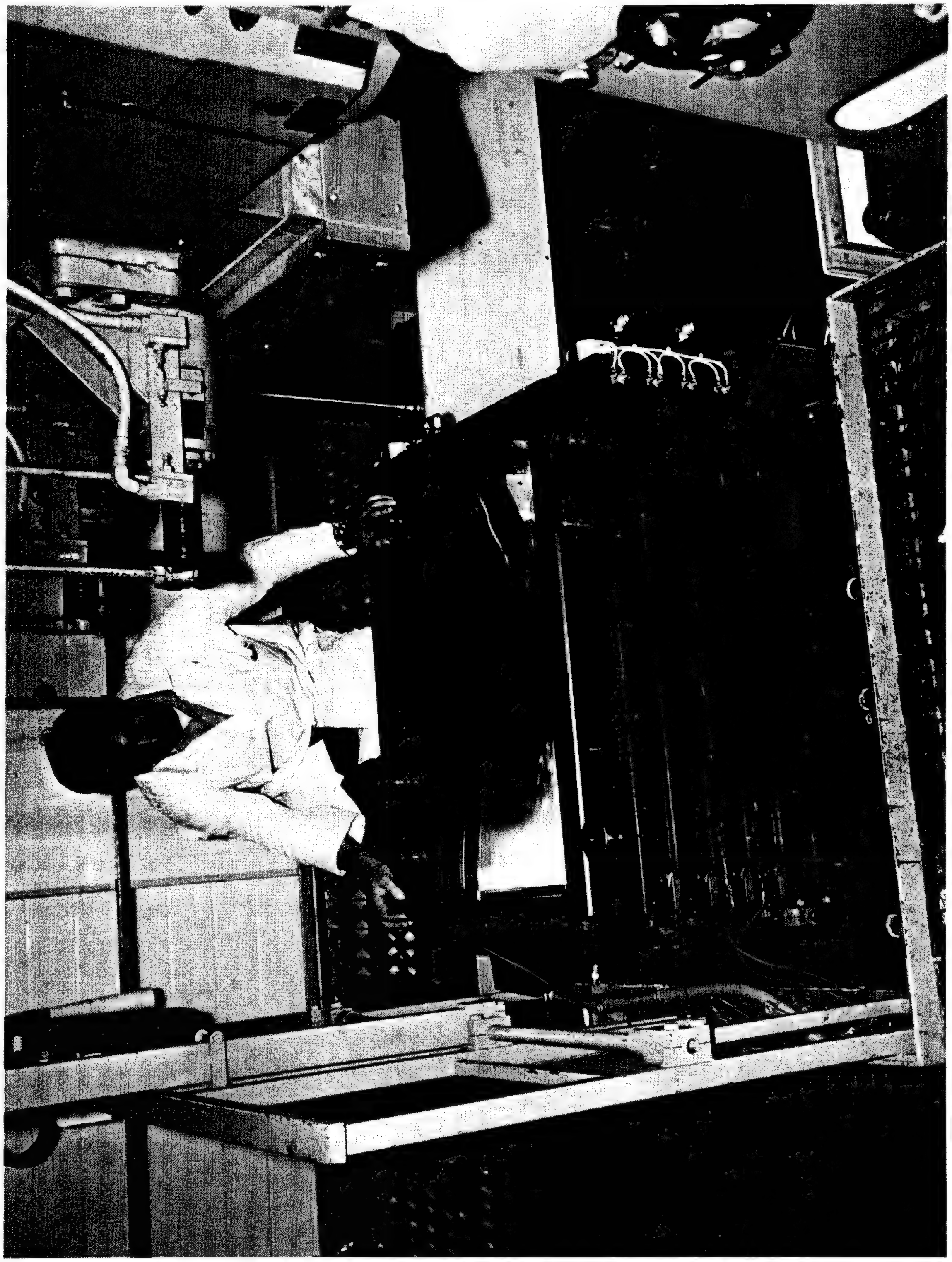


Figure 37. 300-Ton Press, View B.

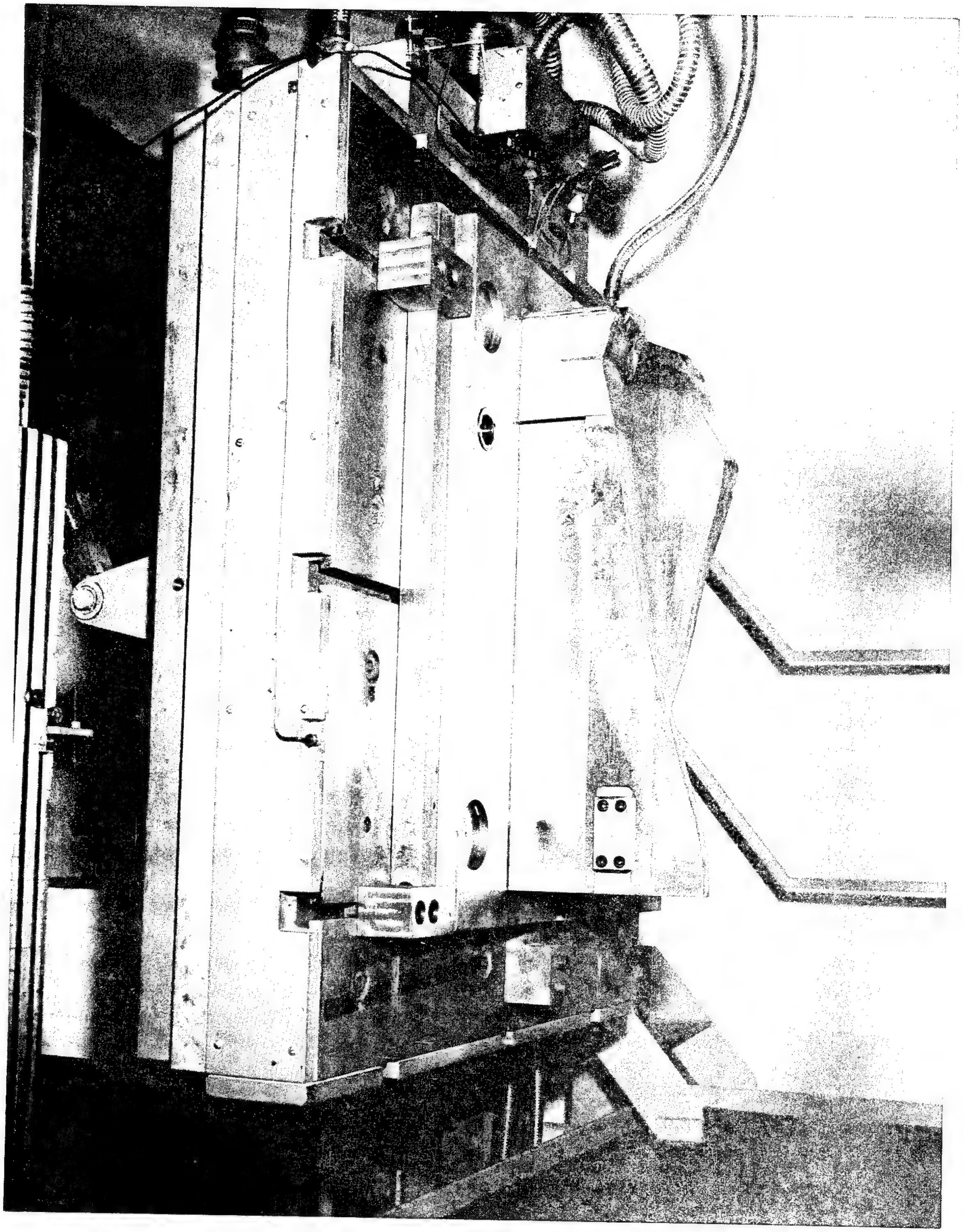


Figure 38. Top-Heated Platen.

4.7.3 Initial Blade Molding

During the initial molding cycle of the first TiCore blade (S/N RL001), problems were encountered whereby the core material on each side of the spar extruded from the blade tip and leading and trailing edges prior to full die closure. The molding process was aborted prior to full consolidation in order to salvage the metallic foils and titanium spar.

After considerable analysis of the problem, the cause was found to be associated with several factors including:

- The high volumetric flow of the viscous AF163 adhesive required to maintain the 0.004-inch (1.016×10^{-4} m) bond line thickness caused hydraulic pressure on the core ply assembly which reacted toward the tip.
- The low coefficient of friction between the spar and the core assembly (Figure 39) caused by the lubrication of the AF163 adhesive created a melon-seed reaction toward the blade tip.
- The boron/aluminum plies extruded less than the composite core because of the delayed wedge action of the polymeric core materials toward the blade tip constriction which finally gripped each B/Al ply causing them to be drawn out of the die. The titanium outer foil ply did not move due to the gripping action of the "dry" die surfaces creating high frictional forces.
- The complete zero degree orientation of the polymeric core material caused chordwise flow during the expulsion of the resin. Fiber was extruded form the preform during molding along the leading and trailing edges.

To fully evaluate the problem, a rectangular "slip test" two-dimensional specimen was designed and fabricated to simulate and demonstrate the basic reaction of the core assembly during molding. Typical foils, adhesive, and a simulated spar were assembled and molded in a 1 x 9-inch (0.0254 x 0.2286 m) mold tool under temperature closure conditions similar to those used to mold the RL001 blade. The specimen behaved identically to the blade, illustrating the core extrusion phonomenon, as shown in Figure 40.

Based on this evaluation of the problem, the following changes were made in the manufacturing process:

- A lower-flow, lower-viscosity adhesive system was selected to replace the AF163 system.
- The AF3185 adhesive system selected is a low-flow version of AF163 on a woven glass scrim carrier fabric which yields a bond line thickness of 0.004 $\pm$ 0.0005 inch (1.016×10^{-4} m $\pm 0.127 \times 10^{-4}$ m). It was believed that the low resin flow and resultant reduced lubrication of the adhesive film, together with the higher coefficient of friction created by the woven glass fabric, would eliminate the problem.

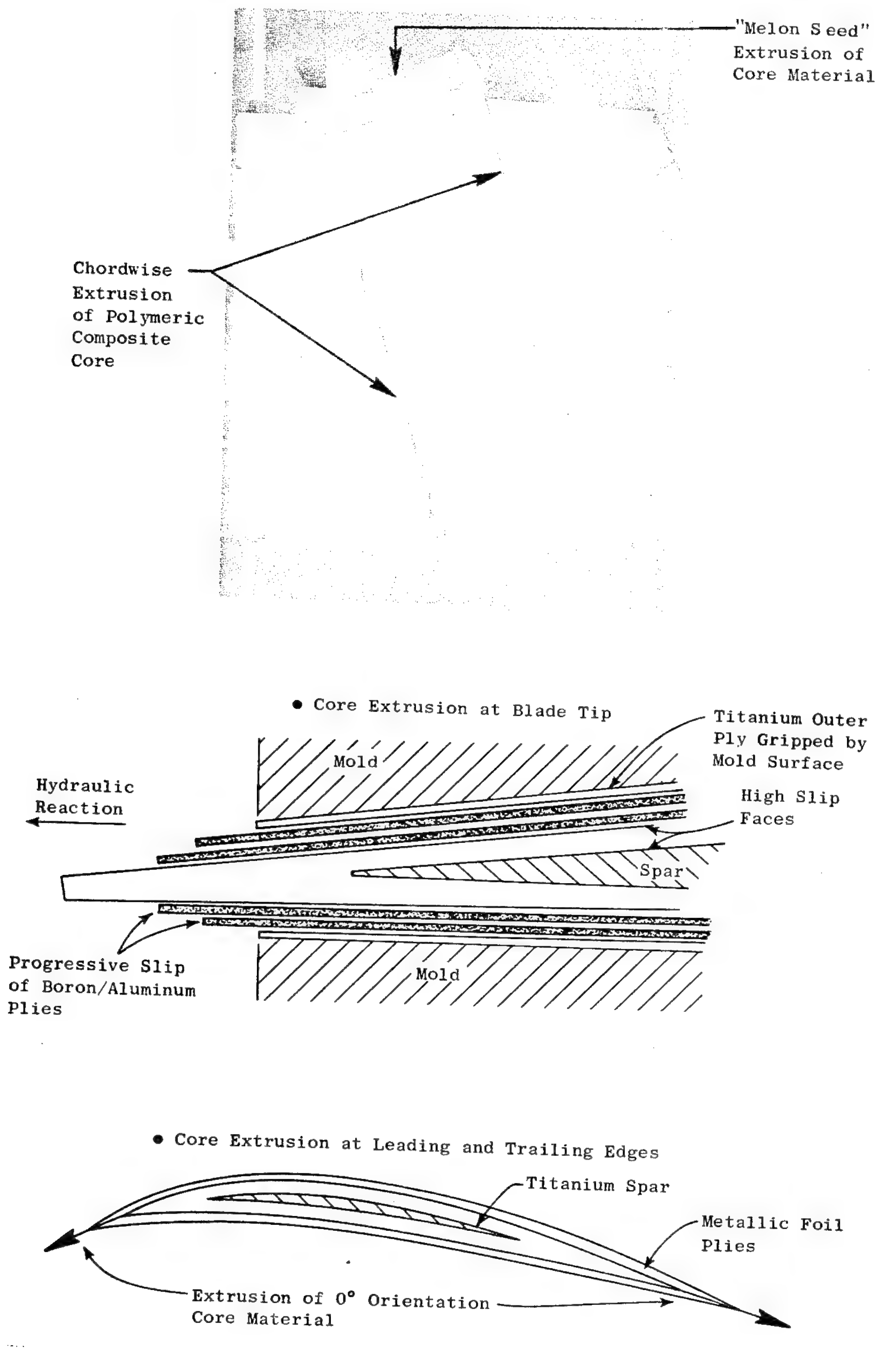


Figure 39. Molding Problems Associated with Core Extrusion on TiCore Blade Design S/N RL001.

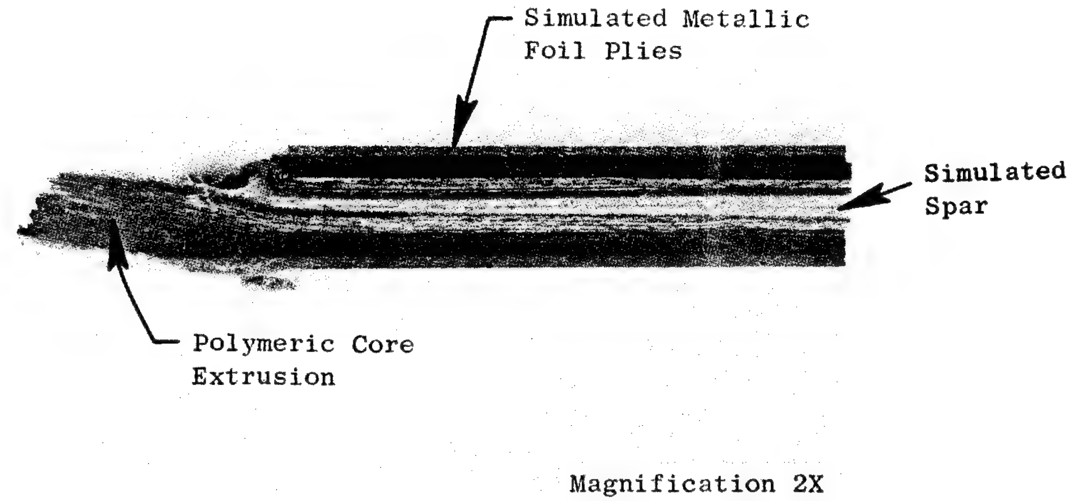


Figure 40. Two-Dimensional "Slip Test" Specimen Illustrating "Melon Seed" Reaction Encountered in S/N RL001 Blade.

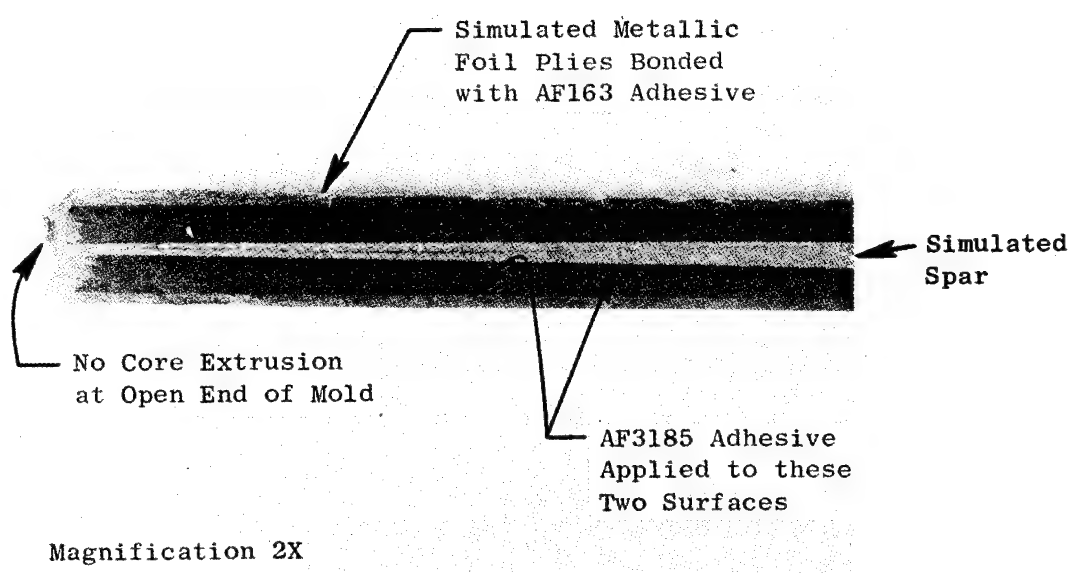


Figure 41. Two-Dimensional "Slip Test" Specimen Showing How "Melon Seed" Reaction Was Eliminated by Use of AF3185 Adhesive.

- The core ply orientation was revised to a 0°/35°/0°/-35° layup to reduce the hydraulic extrusion of fiber in the chordwise direction and also to facilitate the PR288 resin bleeding/venting to the leading and trailing edge zones rather than toward the tip, as is the phenomenon with the 0° layup.

To evaluate the proposed improvements, a slip test rectangular specimen was fabricated using the basic revised construction. The specimen was molded using similar conditions to the original slip test specimen with the tip end of the die open. As shown in Figure 41, no extrusion of the core resulted.

Based on these results, the second TiCore blade (S/N RL003) was fabricated with the revised adhesive film and polymeric core layup assembly and the metallic skins and titanium core salvaged from the RL001 blade. The blade was successfully molded using identical conditions to blade RL001 with only minor signs of extrusion of fiber from the core zone of the blade. The die did not completely close, producing the blade 0.025-inch (6.35×10^{-4} m) oversize at the root and at the blade tip maximum thickness dimensions. Two small areas of slight local distortion in the titanium outer skin were noted, as shown in the visual inspection record (Figure 42). In the zone of the leading edge surface, there were signs of local entrapment of the titanium foil and the die shear surfaces. One local area of slight delamination of the titanium foil was created during removal of the blade molding from the die in the hot condition prior to optimizing the material properties by the succeeding postcure operations.

The second prototype blade (TiCom S/N RL002) was successfully produced using the revised processes and materials employed in the fabrication of TiCore blade S/N RL003. These two prototype blades are shown in Figures 43 and 44.

4.7.4 Blade Destructive Evaluation

Each of the two prototype blades was ultrasonically C-scanned after molding to assess blade quality prior to destructive analysis. Teflon washers were incorporated into the layup of TiCore blade S/N RL003 at four different locations to demonstrate the nondestructive evaluation capability for locating delamination type defects. No detectable disbonds or excessive porosity were shown by the C-scans (with the exception of the Teflon built-in defects) indicating that both blades were well consolidated.

After review and approval of the nondestructive evaluation results with NASA prototype blade, destructive analysis was initiated according to the plan shown in Figure 45.

The test results shown in Table VIII illustrate the high transverse (chordwise) short beam shear values attributable to the 0.007-inch (1.778×10^{-4} m) thick titanium outer skin and/or the internal spar compared to

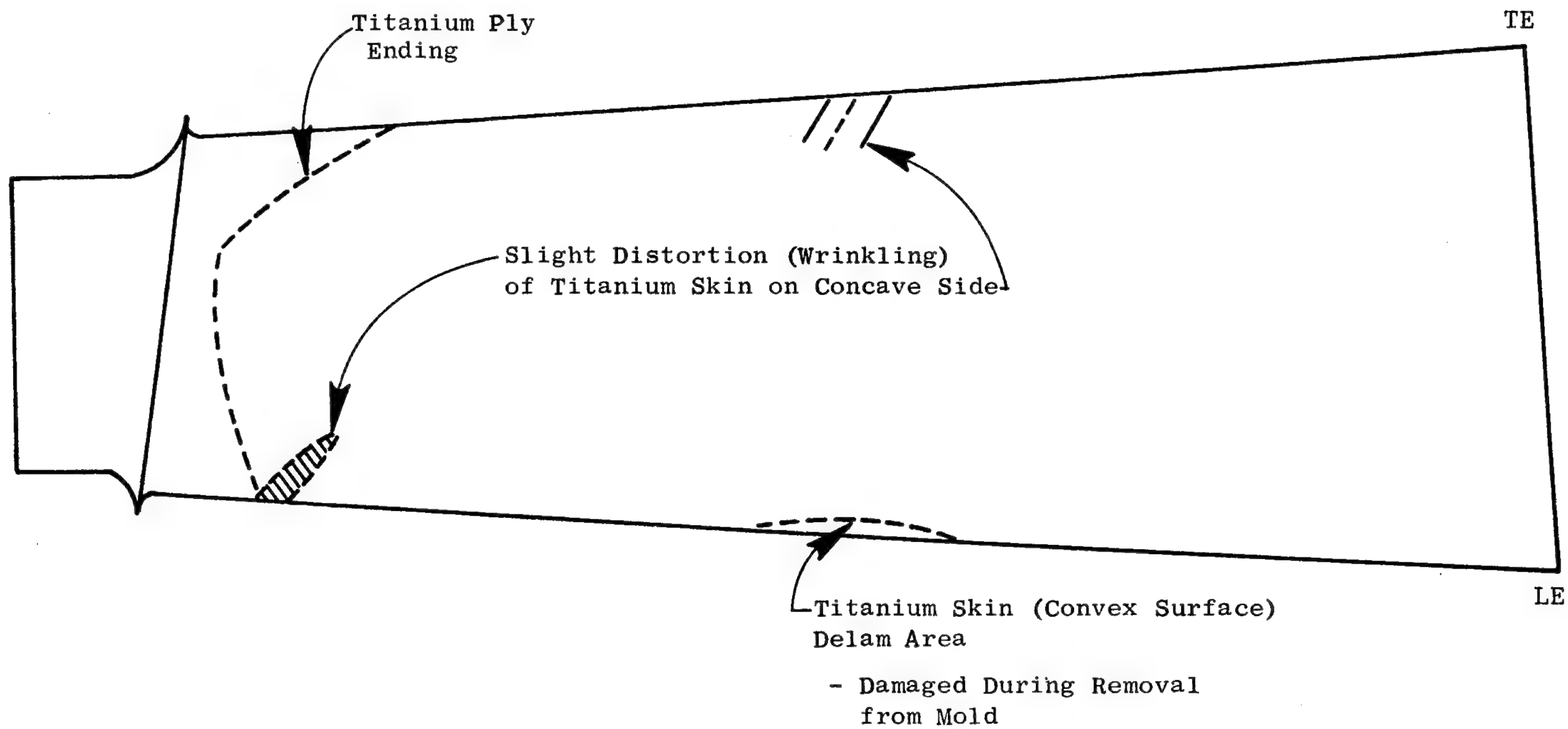


Figure 42. Visual Inspect Record.

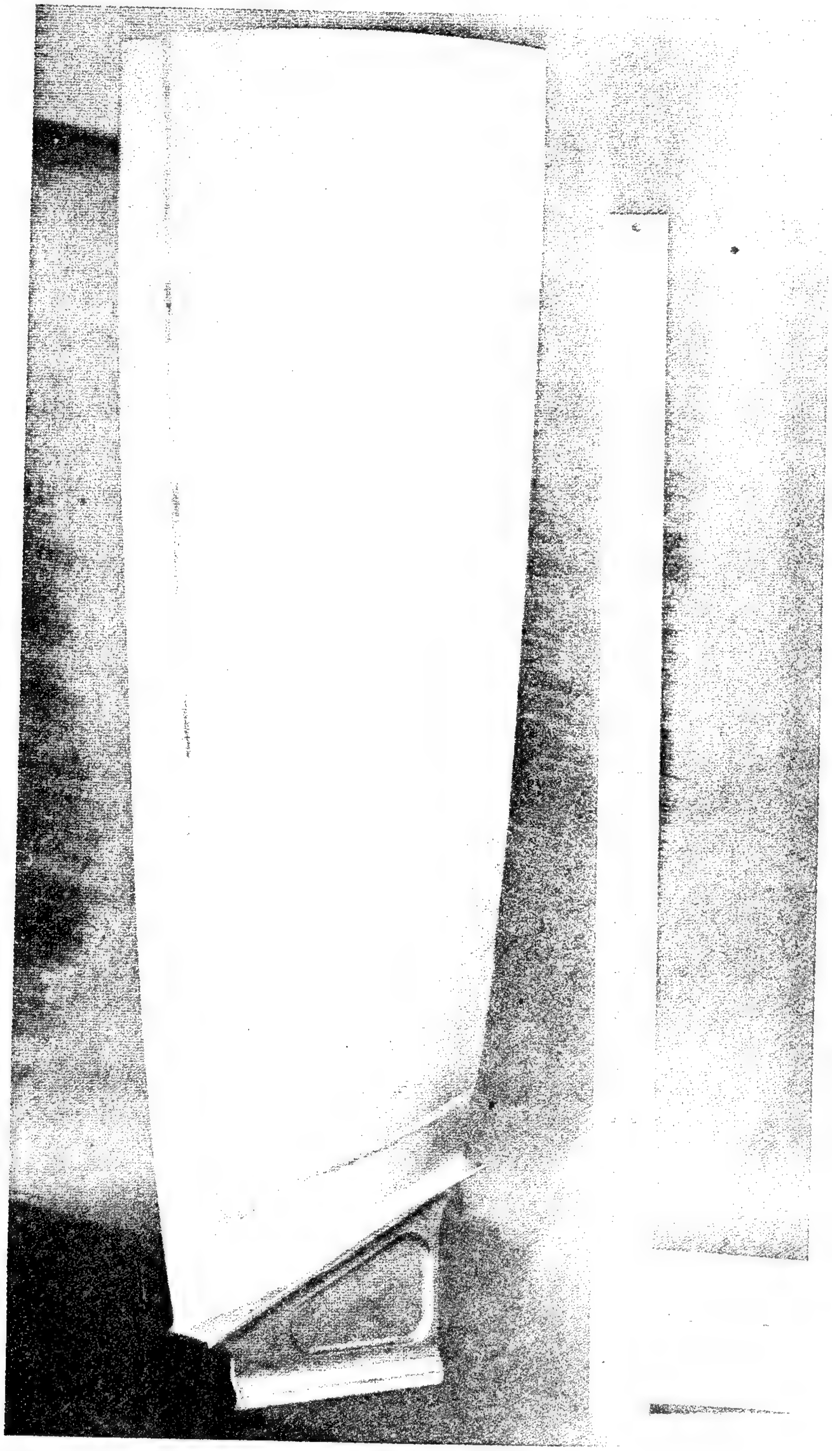


Figure 43. Superhybrid - CF6 TiCom Prototype Blade, S/N RL002.

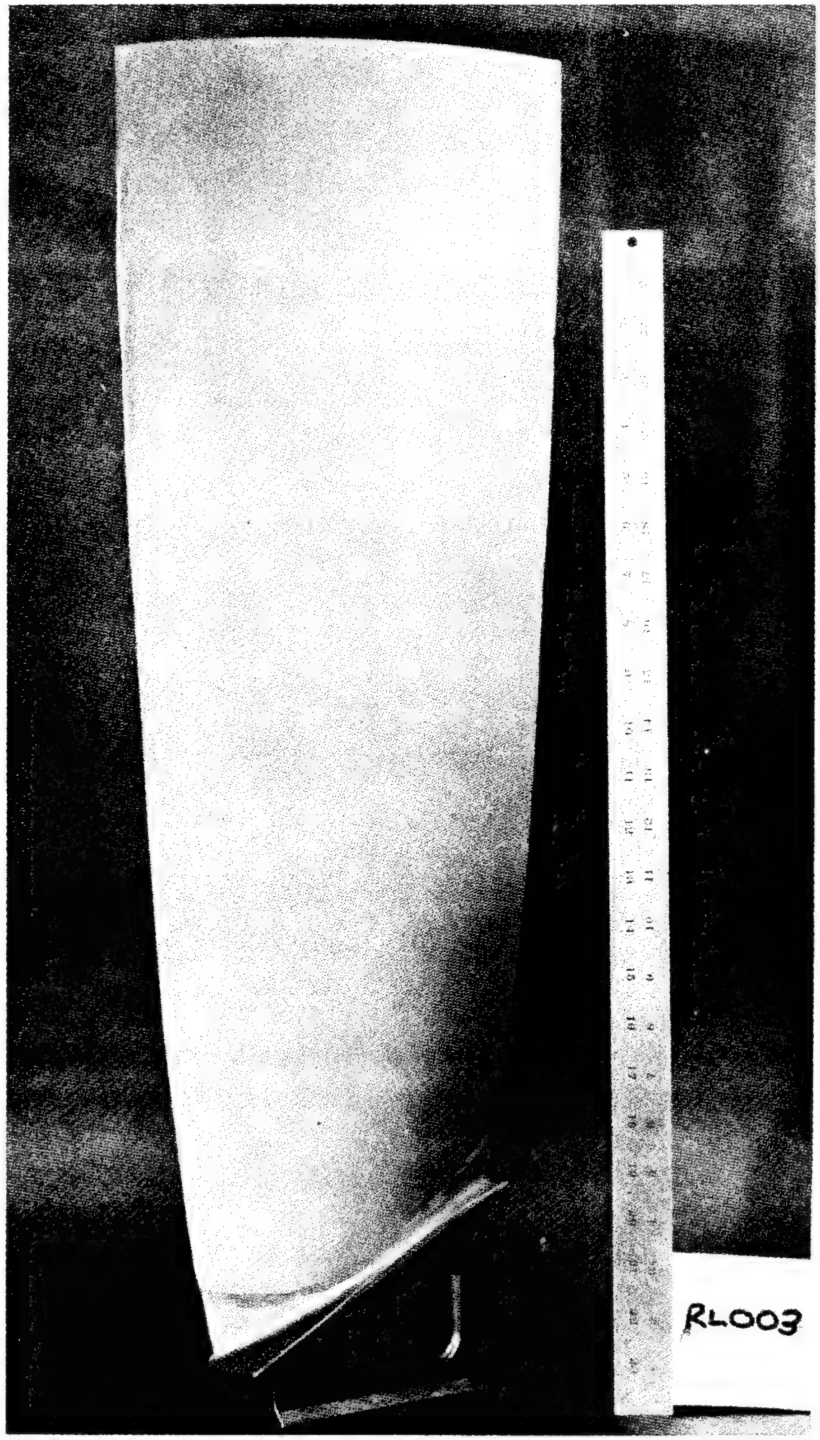
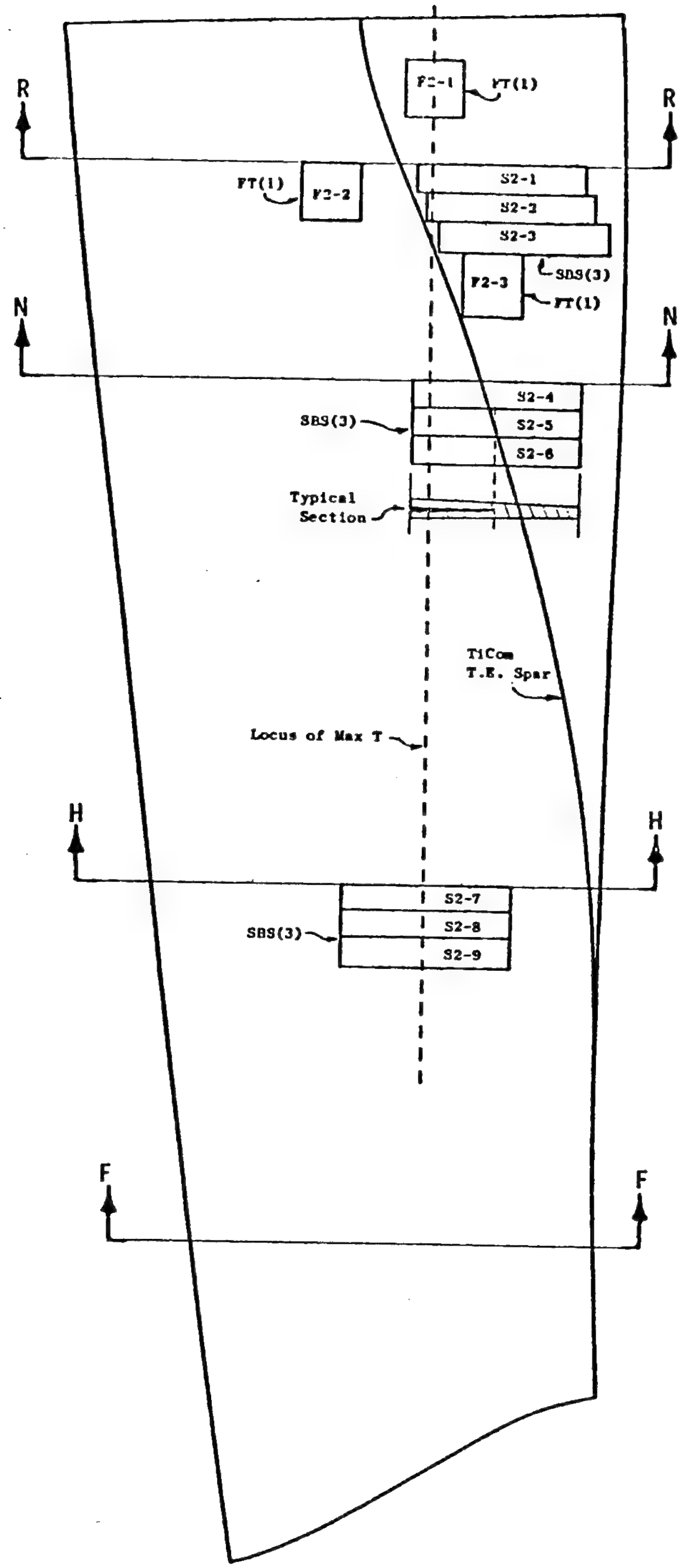


Figure 44. Superhybrid - CF6 TiCore Prototype Blade, S/N RL003.



Destructive Analysis

- Radial Sections at RR, NN, HH, and FF
- Transverse SBS (9 Specimens, 3 Locations) Based upon Average Thickness and L/α Ratio of 5/1
- Flatwise Tensile (3 Specimens)

Figure 45. TiCom Design, S/N RL002.

Table VIII. Short Beam Shear and Flatwise Tensile Data.

(Length/Diameter Ratio = 5/1)

Design	Specimen No.	Short Beam Shear, psi (10^6 n/m^2) 70° F	150° F
Composite Core	S2-1	6,770 (46.67)	-
	S2-2	6,290 (43.36)	-
	S2-3	-	5,700 (39.30)
Part Spar	S2-4	6,650 (45.85)	-
	S2-5	6,580 (45.36)	-
	S2-6	-	4,510 (31.10)
Full Spar	S2-7	11,000 (75.84)	-
	S2-8	11,430 (78.80)	-
	S2-9	-	10,330 (71.22)

Design	Specimen No.	Flatwise Tensile,(1) psi (10^6 n/m^2) 70° F	150° F
Composite Core	F2-1	>4,430 (30.54)	-
	F2-3	-	>2,590 (17.85)
Full Spar	F2-2	>3,630 (25.03)	-

(1) All flatwise test specimens failed in the adhesive bonding the specimens to the test blocks.

a conventional polymeric composite laminate value of ~3 ksi (20.68 x 10^6 n/m^2) for a 0°/35°/0°/-35° layup. Typical specimen failure modes of the three basic designs are shown in Figure 46. The specimens indicate a combination of tensile and shear failures, with the failure initiation probably being tensile. The high shear strength values of the full spar specimens are based on classical methods of calculation which assume the peak shear stress value at the center of the specimen. For these nonisotropic specimens, the failures occurred at the spar-composite interface, which is not at the geometric center of the specimen. Detailed shear calculations were performed which indicated that the maximum shear stress at the failure site was in the 9,000 to 10,000 psi (62.05 x 10^6 m to 68.94 x 10^6 m) range for the room-temperature specimen.

The flatwise tensile specimens all failed cohesively within the Metlbond 328 adhesive used to bond the specimens to the test blocks. Therefore, the laminate strengths are greater than the recorded values. Specimen F2-3 indicated that intraply failure was imminent within the boron/aluminum plies. Figure 47 shows failure commencing through the aluminum Al100 matrix.

The test results indicate that adequate material properties have been achieved in the fabrication of the blade compared to design requirements.

Based upon the results of the destructive analysis of Blade RL002, NASA approval was given for the fabrication of the six impact-test blades.

4.7.5 Test Blade Fabrication

Upon completing successful fabrication and destructive evaluation of the two prototype superhybrid blades, the remaining six blades were successfully fabricated. The total list of all blades fabricated is shown in Table IX. Photographs of the TiCore and TiCom test blades are presented in Figures 48 and 49, respectively.

4.7.6 Blade Quality Assurance Evaluation

To assess overall blade quality including nondestructive and dimensional evaluation, each of the six superhybrid blades underwent strict quality control procedures. A detailed Material Review Board (MRB) review of each blade was conducted to assess overall blade quality and to judge the acceptability of the blades for whirligig testing. All blades were judged acceptable for testing and were given an overall grade between 75 and 85 on a scale of 1 to 100. A blade weight summary is presented in Table X along with nickel-plate hardness and the final grade for each blade. Final blade weights are in close agreement for all blades except TiCom Blade RL009, which is approximately 100 grams heavier because its spar is thicker than the design intent.

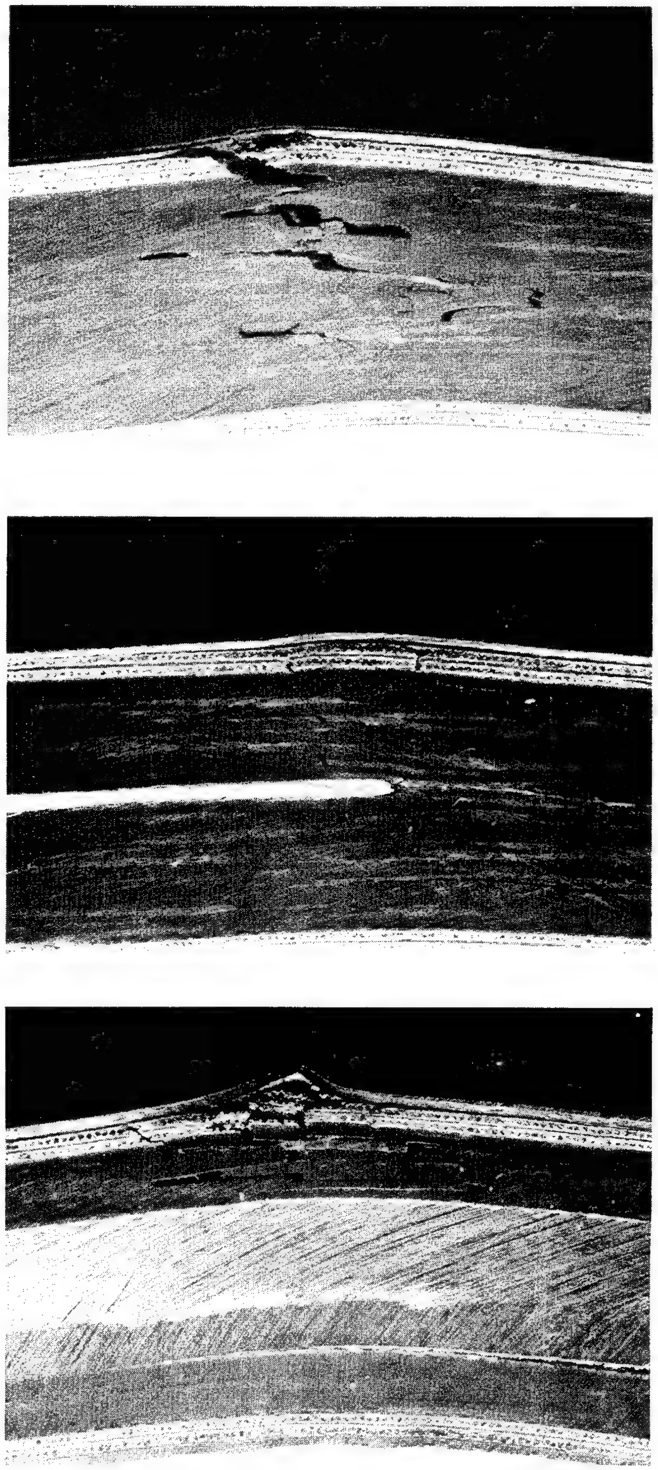


Figure 46. Short Beam Shear Specimens (Superhybrid Blade RL002).

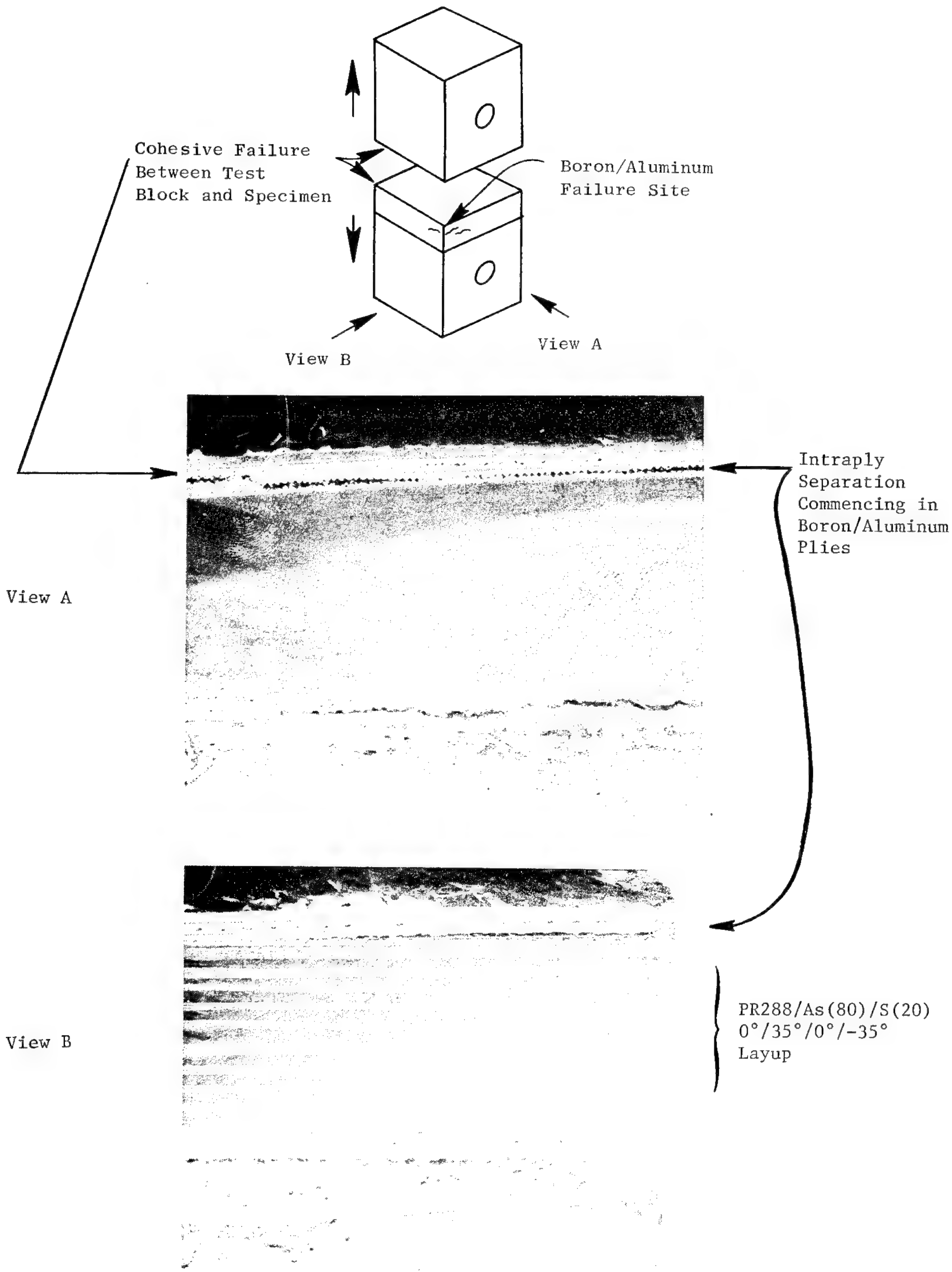


Figure 47. Flatwise Test Specimen Superhybrid Blade RL002. (Specimen F2-3)

Table IX. Total List of Superhybrid Blades Fabricated.

Serial Number	Blade Design	Comments/Status
RL001	TiCore	Scrapped during molding. Spar and metallic skins salvaged and reused in Blade RL003.
RL002	TiCom	Destructive-analysis blade specimens evaluated for mechanical properties.
RL003	TiCore	Nondestructive-evaluation calibration blade - built-in defects included.
RL004	TiCore	Impact-test blade - leading edge plating.
RL005	TiCore	Impact-test blade - leading edge benching after plating.
RL006	TiCore	Impact-test blade - wire mesh being applied.
RL007	TiCom	Impact-test blade - finishing.
RL008	TiCom	Impact-test blade - nondestructive evaluation prior to finishing.
RL009	TiCom	Impact-test blade - nondestructive evaluation prior to finishing.

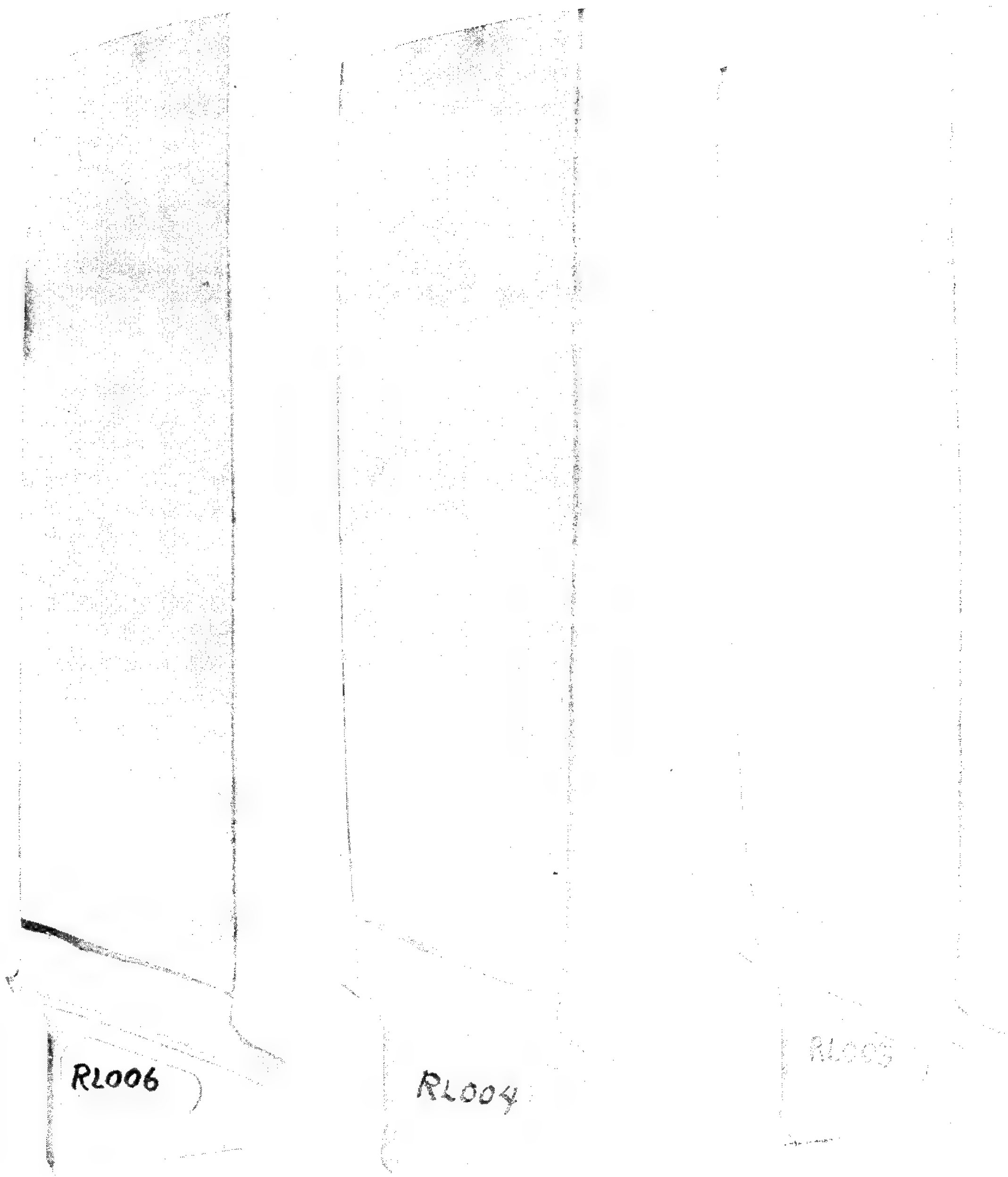


Figure 48. Superhybrid Composite Blades (TiCore) After Manufacture (Convex Surface).

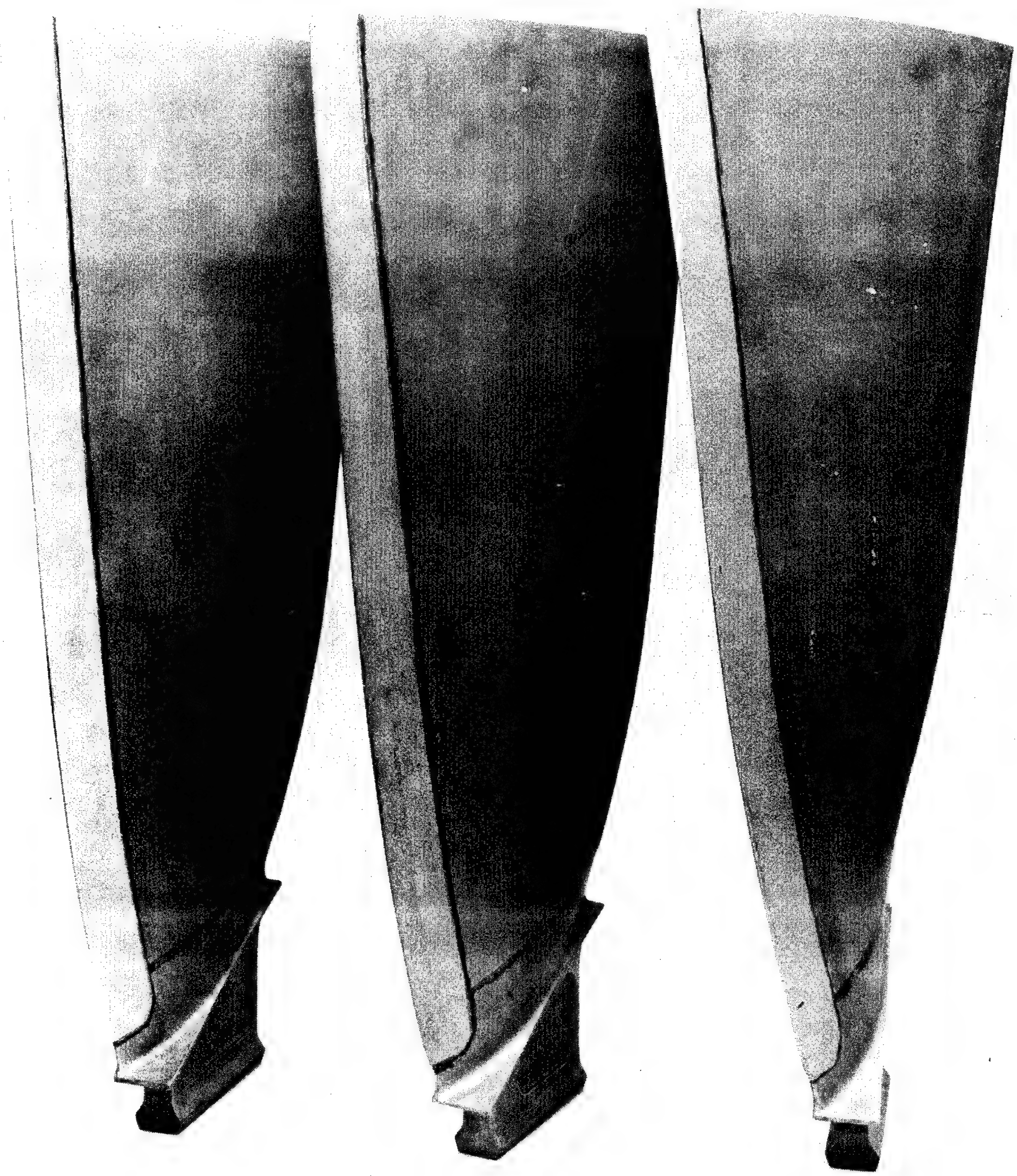


Figure 48. Superhybrid Composite Blades (TiCore) After Manufacture (Concave Surface) Concluded.

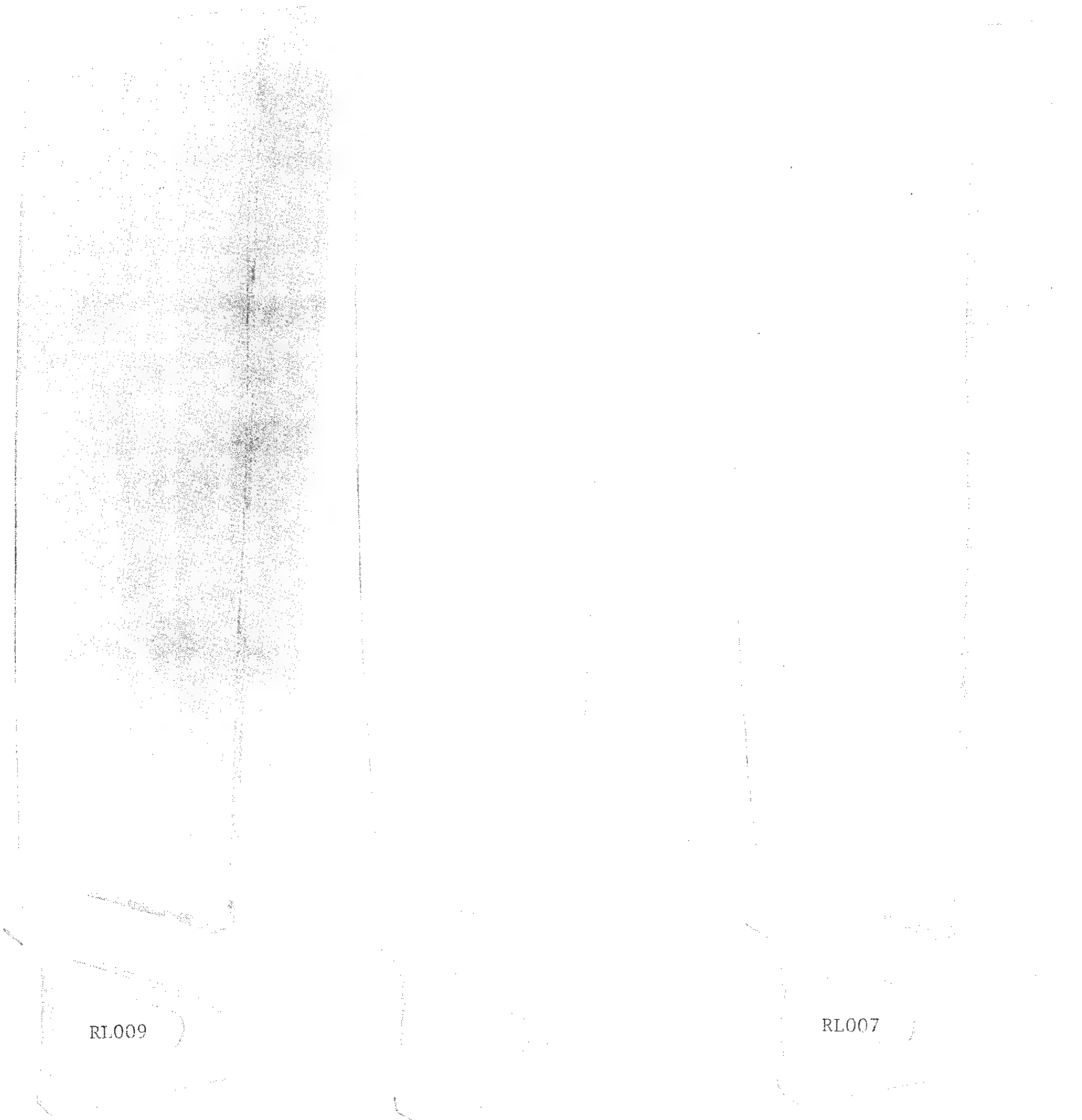


Figure 49. Superhybrid Composite Blades (TiCom) After Manufacturing (Concave Surface).

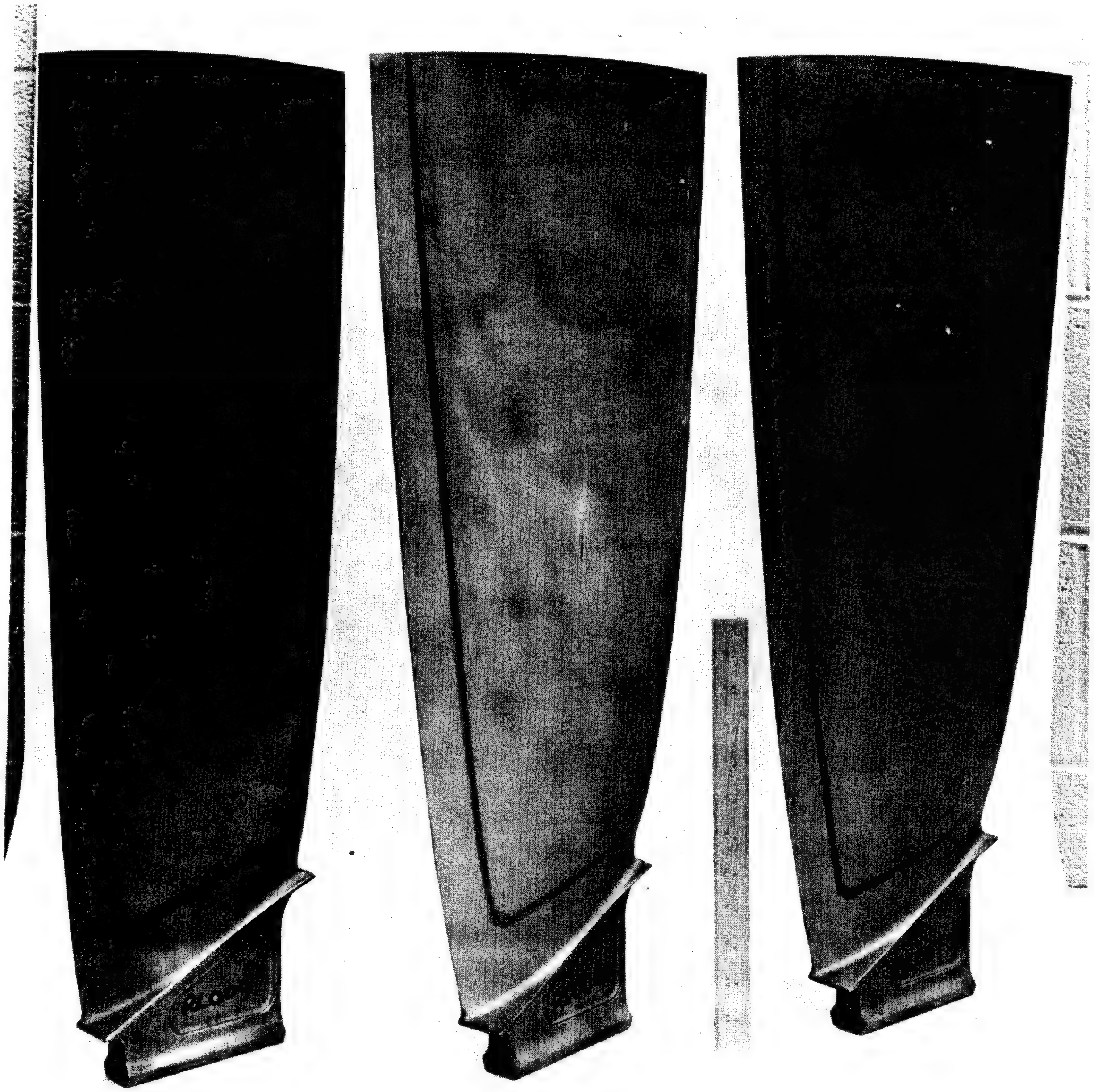


Figure 49. Superhybrid Composite Blades (TiCom) After Manufacturing (Convex Surface) Concluded.

Table X. CF6-50 Superhybrid Impact Test Blade Data.

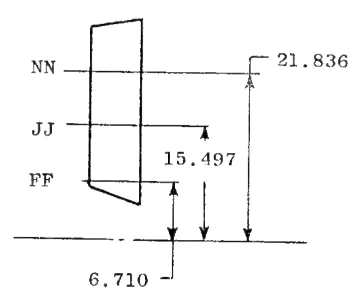
NAS3-20402

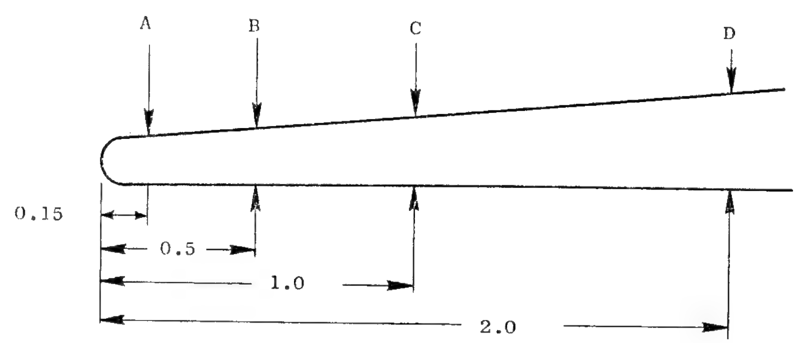
	TiCore Designs			TiCom Designs		
Test Blade Data	RL004	RL005	RL006	RL007	RL008	RL009
Spar Serial Number	THB34421	THB15028	AMDA7621	AMD66617	THB29666	A4993
Spar Weight (gm)	2188	2209	2210	2705	2715	2882
Polymeric Core Preform Weight (gm)	550	559	535	367	370	342
Final Preform Weight (gm)	3429	3474	3452	3564	3655	3740
Molded Weight (gm)	3366	3369	3373	3573	3585	3676
Trimmed Weight (gm)	--	--	--	3520	3530	3622
Blade Weight with Leading Edge Protection (gm)	3575	3550	3604	NA	NA	NA
Nickel-Plate Hardness (Rockwell C)	35	28	30	NA	NA	NA
Final Blade Weight (gm)	3484	3507	3501	3520	3530	3622
Material Review Board Grade (0 to 100)	75	95	85	80	85	80

Dimensional inspection on each blade consisted of taking thickness measurements at three airfoil sections: the root, the pitch, and the tip. At each span location, four leading edge thickness measurements and maximum blade thicknesses were taken. For the TiCore blades, the leading edge nickel chordal thickness was also obtained by comparing chordal dimensions before and after plating. A summary of these data is shown in Table XI along with blueprint tolerance. The data summary shows that leading edge thicknesses for the TiCore blades in the first 1.0 inch (0.0254 m) back from the leading edge were considerably above the blueprint tolerance. This condition is the result of applying the wire mesh/nickel-plate coating directly on the as-molded TiCore blades. Because the leading edge configuration had both boron/aluminum and titanium foil plies, and because there would be complications involved in providing inserts in the die to achieve a thinner airfoil section, it was decided to accept the thicker leading edge for the TiCore blades.

Table XI. Dimensional Inspection of CF6 Unshrouded Superhybrid Composite Blades.

	FF						JJ						NN					
	A	B	C	D	Max	N_i PLATE (nose)	A	B	C	D	Max	N_i Plate	A	B	C	D	Max	N_i Plate
Blade S/N	0.080	0.107	0.156	0.252	0.379	0.065	0.068	0.083	0.114	0.175	0.280	0.065	0.060 0.074	0.080	0.109	0.164	0.923	0.065
RL004	0.162	0.175	0.213	0.271	0.397	0.080	0.140	0.154	0.178	0.211	0.317	0.079	0.140	0.146	0.168	0.197	0.314	0.073
RL005	0.152	0.173	0.215	0.267	0.397	0.076	0.139	0.155	0.178	0.208	0.315	0.080	0.137	0.152	0.174	0.200	0.314	0.080
RL006	0.156	0.170	0.210	0.271	0.398	0.098	0.147	0.155	0.177	0.208	0.312	0.055	0.140	0.148	0.169	0.195	0.313	0.067
RL007	0.072	0.112	0.160	0.281	0.390	-	0.064	0.101	0.137	0.204	0.312	-	0.052	0.081	0.114	0.180	0.309	-
RL008	0.073	0.112	0.162	0.291	0.403	-	0.063	0.095	0.128	0.205	0.315	-	0.051	0.070	0.099	0.165	0.312	-
RL009	0.076	0.121	0.169	0.282	0.393	-	0.043	0.102	0.140	0.207	0.310	-	0.062	0.090	0.120	0.170	0.307	-





5.0 BLADE TESTING

5.1 BENCH FREQUENCIES

Each of the six superhybrid test blades underwent bench frequency testing in the clamped-end cantilever condition. Table XII presents the results of this testing for the first five frequencies. These data show good consistency in frequencies among superhybrid blades and modest improvements in stiffness over unshrouded titanium blades.

5.2 WHIRLIGIG TESTING

The initial whirligig testing consisted of conducting a 100-cycle spin test on a TiCore and a TiCom blade at 110% speed (4488 rpm). Cyclic testing of both blades was completed successfully, with no adverse effects, as evidenced by several through-transmission nondestructive test (NDT) hand scans of each blade at various cycle intervals throughout the testing. Blade temperatures during cyclic testing were held below 225° F (107.2° C) at the tip and below 200° F (93.3° C) at the root. Temperature measurements were made by a combination of temperature dots mounted to the blade and an air thermocouple in the shroud at the blade tip.

After cyclic testing, whirligig impact testing was initiated according to the test plan shown in Table XIII. Of the six blades planned for testing, three TiCore and one TiCom were tested. A typical photograph of the test setup including disk, blade, and bird injector is shown in Figure 50.

Test results for all impact testing are summarized in Table XIV. This summary shows that after the initial starling impact on each blade design, the TiCore blade suffered the least damage and that this was limited to the attachment of the nickel plate to the wire mesh. The TiCom blade suffered considerably more damage under starling impact: its spar separated from the shell, causing delamination over 50% of the airfoil. Based on the results of this TiCom blade test, it was believed that further testing of the two remaining TiCom blades with larger bird slices would result in complete failure and loss of the shell of the blades. Therefore, these tests were eliminated from the test program.

As shown in Table XIV, three additional tests were conducted on the TiCore blades. The second starling impact on the TiCore blade (RL005) resulted in nickel-plate separation similar to the initial TiCore test (RL006). In an attempt to determine whether any structural damage was done to either of the two TiCore blades, the nickel-plate/wire mesh leading-edge protection was removed for further NDT evaluation. With the exception of a slight buckle in the titanium surface ply of the TiCore blade RL004, there was no damage to the blade after removing the leading-edge protection. With improvements in the nickel-plate adhesion or the substitution of a suitable alternative leading-edge protection system, it is believed that the no-damage starling impact requirement can be achieved with a TiCore blade design.

After stripping the nickel plate/wire mesh from TiCore Blade RL006, it was decided to retest it in the unprotected thin leading-edge configuration to determine the degree of protection given by the leading-edge protection system. The results of this test showed that without leading-edge protection and/or increased leading-edge thickness, local fracture of the surface plies took place (Figure 51). This blade suffered local fracture of the convex titanium/boron/aluminum layers with a 40 gram weight loss and a 15% airfoil delamination.

The damage resulting from the impact of a 9-ounce (0.255 kg) slice of a pigeon, which is nearly equivalent to the ingestion of a 1-1/2 pound (0.680 kg) bird at aircraft takeoff conditions, resulted in considerable local damage and delamination, with an attendant blade weight loss of approximately 8% (Figure 52). This damage may be acceptable, depending on whether the engine can maintain 75% power without incurring subsequent damage which would result in engine shutdown.

Table XII. Bench Frequencies of CF6 Superhybrid Composite Blades.

	Hz				
	1F	2F	1T	3F	4F
RL004	30	92	186	230	442
RL005	30	94	184	232	452
RL006	30	94	184	232	446
RL007	26	88	180	218	434
RL008 TiCom	28	90	189	220	436
RL009	28	88	182	214	428
CF6 Titanium Blade					
Unshrouded	22	76	152	–	–
Shrouded	176	382	458	–	–

Table XIII. Whirligig Impact Test Plan.

Blade		#1	#2	#3
TiCom	Bird	3 oz (0.085 kg)	8 oz (0.226 kg)	24 oz (0.680 kg)
	Slice	3 oz (0.085 kg)	6 oz (0.170 kg)	9 oz (0.255 kg)
Internal Spar	Bird	3 oz (0.085 kg)	8 oz (0.226 kg)	24 oz (0.680 kg)
	Slice	3 oz (0.085 kg)	6 oz (0.170 kg)	9 oz (0.255 kg)

- Impacts at 75% Span
- 3850 rpm
- 23° Incidence Angle
- Simulates 300 ft/sec (91.44 m/sec) Takeoff Velocity

Table XIV. Superhybrid Test Results.

TiCore Blades	Slice Size	Equivalent Bird Size	Remarks
Shot 1 RL006	2.84 oz (0.080 kg)	3.0 oz (0.085 kg)	Nickel-plate Separation
Shot 2 RL004	9.0 oz (0.255 kg)	1.5 lb (0.680 kg)	Local Fracture
Shot 3 RL005	2.86 oz (0.081 kg)	3.0 oz (0.085 kg)	Nickel-plate Separation
Shot 4 RL006 (No Leading Edge Protection)	3.0 oz (0.085 kg)	3.0 oz (0.085 kg)	Local Fracture
TiCom Blade			
Shot 1 RL008	2.90 oz (0.082 kg)	3.0 oz (0.085 kg)	Severe Delamination
RL007	Not Tested		
RL009	Not Tested		

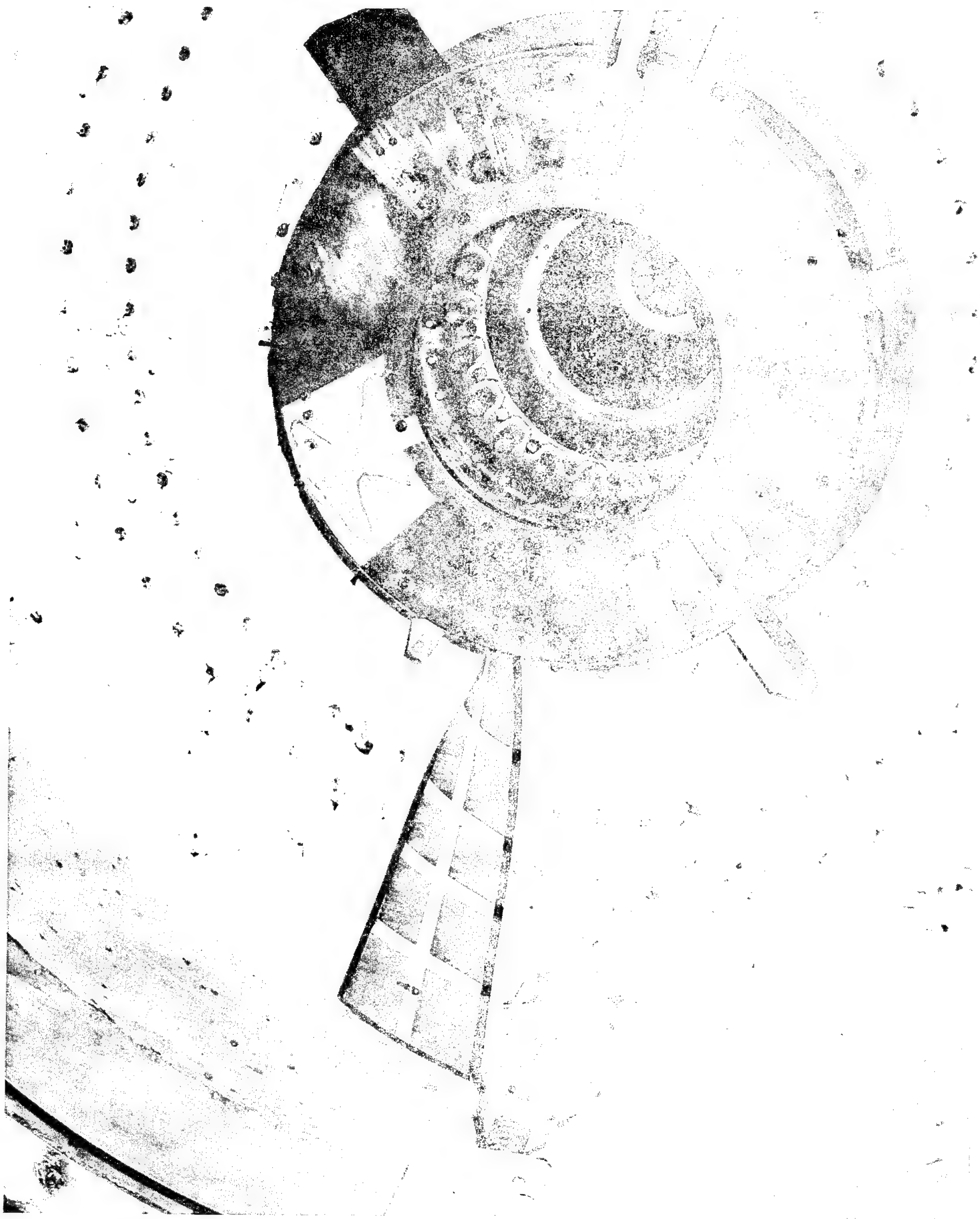


Figure 50. Superhybrid Blade Whirligig Impact Test Setup.

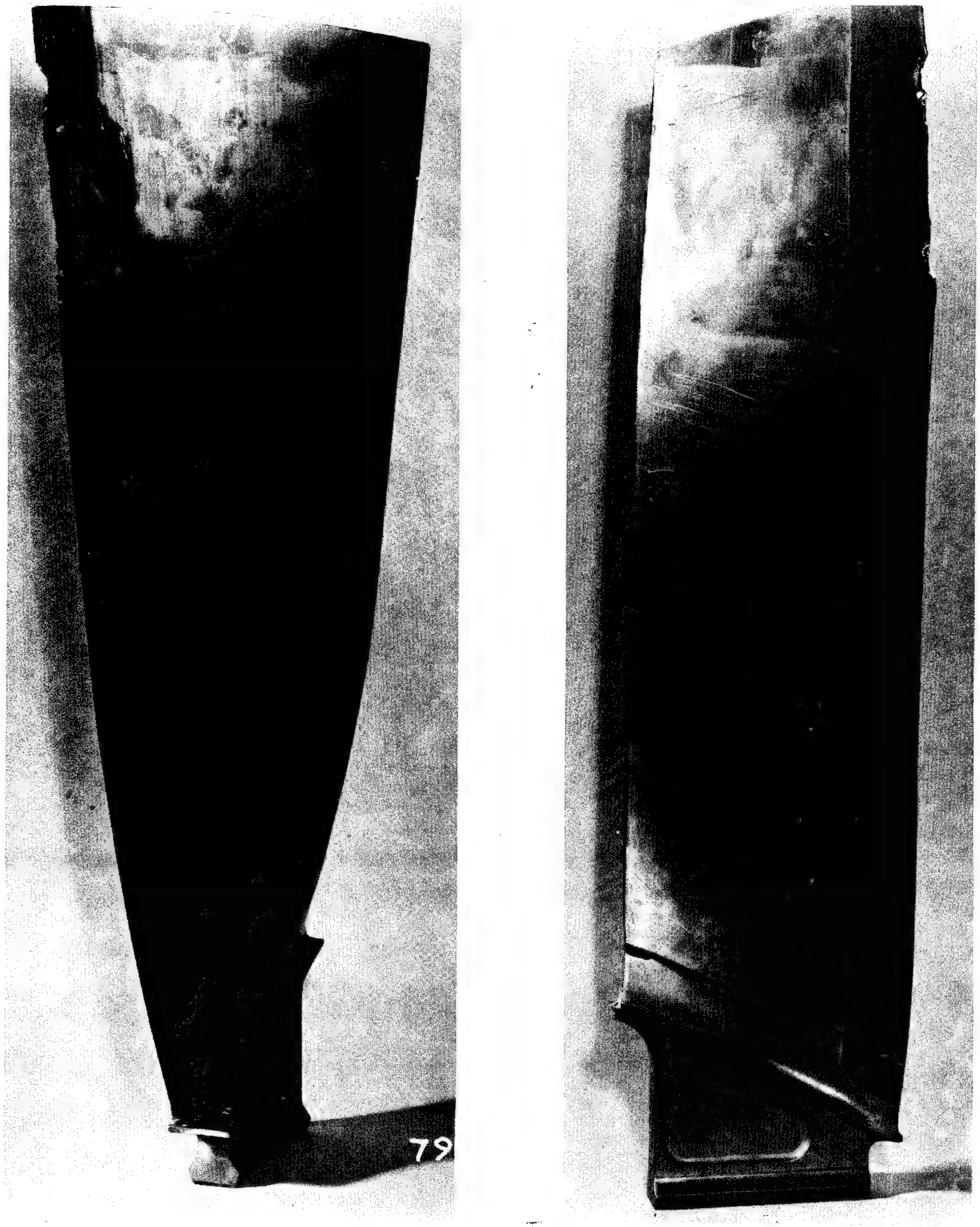


Figure 51. TiCore Superhybrid Blade (RL006) Without Leading Edge Protection, Shown After Impact Testing of 3.0-ounce Starling.

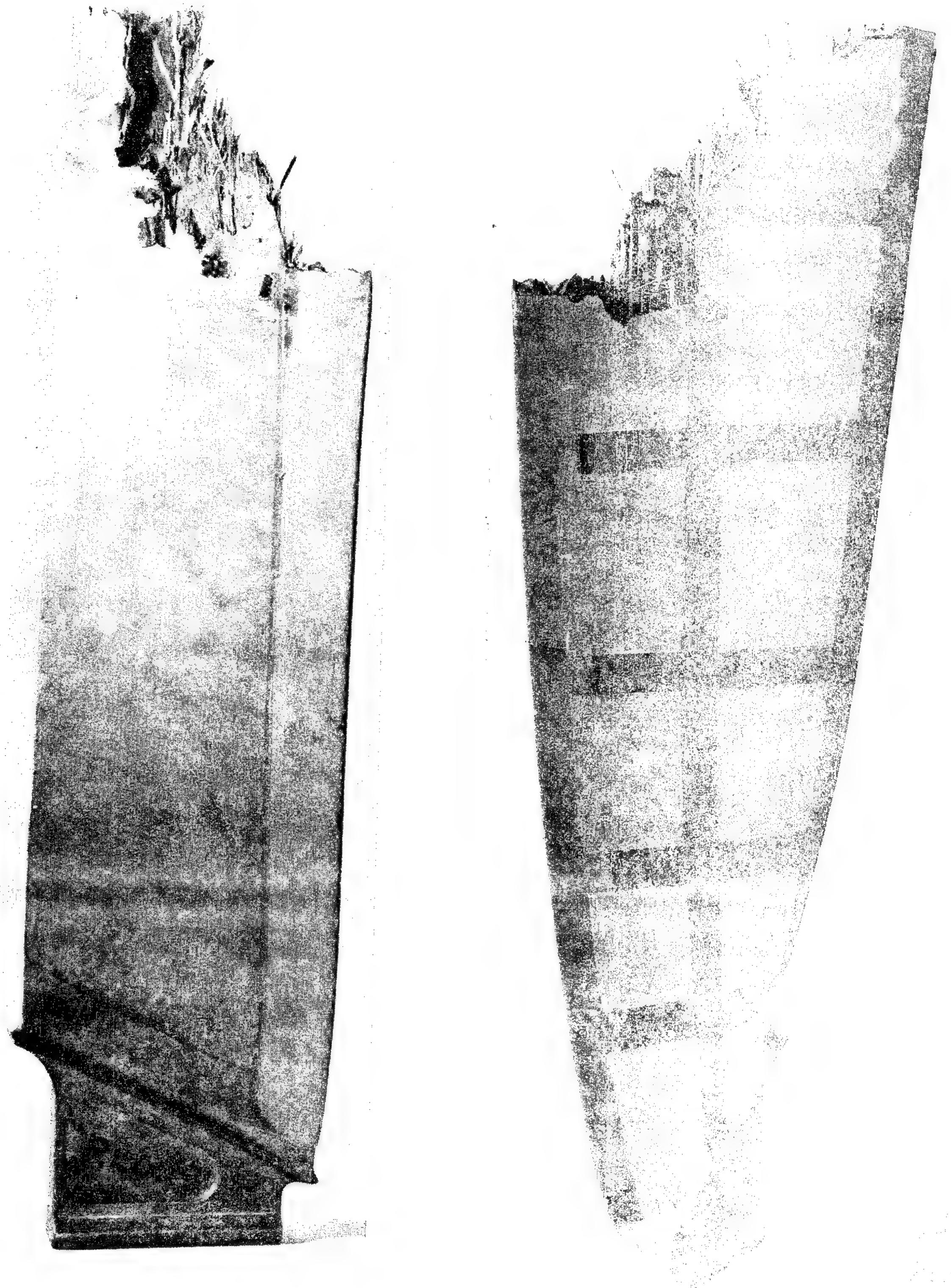


Figure 52. TiCore Superhybrid Blade (RL004) Shown After Whirligig Impact Testing of 1.5-pound Bird.

6.0 CONCLUSIONS

This program demonstrated that the superhybrid material concept is a feasible one which can be utilized to produce lightweight, high-quality, large fan blades having good structural integrity. The manufacturing process developed during this program demonstrated that several prototype blades could be manufactured with good uniformity and dimensional control and that the process is capable of being scaled up for preproduction quantities of blades. Whirligig testing confirmed that both the TiCore and TiCom blade designs are feasible from the standpoint of steady-state operating conditions; but the TiCore blade proved to be the superior design from a bird impact resistance standpoint.

During impact testing, the only shortcoming found in the TiCore blade design was local separation in the adhesion of the nickel-plate leading-edge protection system.

Other specific conclusions reached from this program include:

- Steady-state operating conditions were successfully achieved on both blade designs during spin testing, including overspeed and cycle testing.
- Satisfactory results were achieved on the program.
- The superhybrid concept is a sound one and has considerable flexibility to make further improvements.
- Blade FOD resistance was good considering this initial development effort.
- Large bird damage to the TiCore blade exceeded the desirable limit of 5% weight loss; however, this may be acceptable, depending on:
  - rotor unbalance capability
  - the amount and degree of secondary damage
  - the ability of the engine to maintain 75% power

7.0 RECOMMENDATIONS

The superhybrid material system should continue being developed for ultimate application in gas turbine engine components. Emphasis should be in the following areas:

- A blade refinement program emphasizing leading edge development and aeromechanical design intent
- A materials evaluation phase directed toward further improvement and evaluation of various superhybrid materials and related benefits, including the use of integral titanium composite materials, particularly the use of a complete wrap-around of the outer titanium plies
- A manufacturing study program to assess low-cost manufacturing methods for superhybrid blades
- An applications study to investigate other applications for superhybrid material in gas turbine engines

APPENDIX

Typical Set of Manufacturing Process Sheets for

Superhybrid Blades

ROUTING CARD

Part Name	Part Number	Quality Level	Serial No.
Blade, Superhybrid - CF6 (Center Spar)	4013057-P01	ZZ	

Operation Number	Operation Description	Material and Process Data	Operator Name	Date Performed
5	Generate Ply Patterns	Spar Number ____		
10	Cut out Laminae	Prepreg Lot Number ____		
20	Preforming	Polymeric Preform Weight ____ g		
30	Spar Surface Preparation	Pasa-Jel Lot No. ____ Primer Lot No. ____ Spar Weight ____ g		
40	Titanium Skin Surface	Pasa-Jel Lot No. ____ Primer Lot No. ____ Skin Weight ____ g		
50	Boron-Aluminum Laminae Preparation	Primer Lot No. ____ Laminae Weight ____ g		
60	Adhesive Application	Adhesive Lot No. ____ Adhesive Weight ____ g		
70	Final Preform Assembly	Final Preform Weight ____ g		
80	Hot Press - Cure - Postcure			
90	Deflash - Bench - Trim	Molded Weight ____ g Trimmed Weight ____ g		
100	Visual Inspect			
110	Dimensional Inspect			
120	Ultrasonic Inspect			

ADDITIONAL INFORMATION

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R O U T I N G   C A R D

Part Name	Part Number	Quality Level	Serial No.
Blade, Superhybrid - CF6	4013057-P01	ZZ	

Operation Number	Operation Description	Material and Process Data	Operator Badge No.	Date Performed
130	Application of Wire TiCore only (4013057-989) 316 SS 100 Mesh Wire Cloth P/O No. Lot No.	AF163 Adhesive Lot No. • Blade Weight Prior to Adding Wire Mesh ____ gms • Blade Weight After Adding Wire Mesh ____ gms		
140	Nickel Plate (TiCore Only)	Blade Weight After Plating ____ gms		
150	LE Benching (TiCore Only)	Blade Weight After Benching ____ gms		
160	Ultrasonic Inspection of LE (TiCore Only)			
170	Final Inspection	Final Blade Weight ____ gms		
180	MRB Review			
190	Clear Paper Work			

ADDITIONAL INFORMATION

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OPERATION SHEET

Issue Date ______ Revision No. ______ Page 1 of 1

PART NAME TiCom/TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013-57-771P01 4013057-780P01	OPERATION Ply Pattern Generation	OPERATION NO. 5

OPERATION NO.	OPERATION DESCRIPTION
1	Select spar for specific blade and locate mold tool (GM 21778-1).
2	Produce Plastic Impression of Remaining Cavity (External Shape Minus Spar). a) Coat mold tool with release agent. b) Coat spar with release agent. c) Mix sufficient catalysed polyester "body filler" material and apply to spar and mold surfaces. d) Position spar in mold cavity with support "buttons" to ensure that it is centrally located. e) Close mold tool, expell surplus material and allow to room temperature cure until hard. f) Remove blade/spar molding from the die and apply coating of blue marking spray paint. g) Using a "pointed" micrometer set at 0.020-inch increments; lightly scribe the model surface to produce topographical contour lines. h) Transcribe contour profiles from the model into developed flat patterns.
3	Copy of the topographical layout of the blade to be inserted in the specific blade file.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION__APPROVALS

OPERATION SHEET

Issue Date ________ Revision No. ________

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Cut Out Laminae	10

OPERATION NO.	OPERATION DESCRIPTION
1	Remove PR288-80As/20 "S" glass prepreg from freezer. Allow prepreg to warm to room temperature (1-2 hours) before removing prepreg from plastic enclosure. Remove prepreg from plastic enclosure only when ready to use.
2	Prepare 2-ply sheets of prepreg to make 0.010-inch thick laminae.
3	Obtain laminae templates CC4 through CC15 and CV4 through CV15. Cut out prepreg laminae-orientation per sketch Sheet 2. Mark laminae numbers on pre-preg backing material of each laminae.
4	Stack prepreg laminae in sequence - C/V and C/C separated. Hold stacks together with paper tape. Place laminae stacks in plastic storage bag and seal. Return to 0° F storage if kit is not to be used within 24 hours.
5	Sign off routing card Operation 10.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

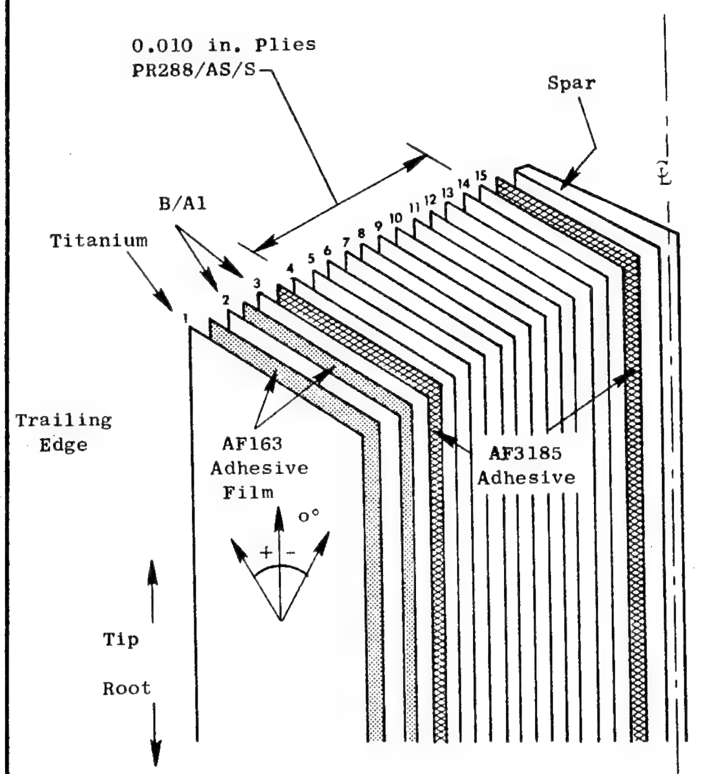
OPERATION SHEET

Issue Date ______ Revision No. ______ Page 2 of 2

PART NAME	PART DRAWING NO.	PART SERIAL #	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01		Cut Out Laminae	10

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS

Basic Diagramatic Half Preform Layup



Ply No. C/C	Ply No. C/V	Material	Orientation
1	1	Titanium 0.008 in.	N.A.
2	2	Boron-Alum 0.007 in.	-15°
3	3	Boron-Alum 0.007 in.	+15°
4	4	PR288/AS/S 0.010 in.	0°
5	5	PR288/AS/S 0.010 in.	-35°
6	6	PR288/AS/S 0.010 in.	0°
7	7	PR288/AS/S 0.010 in.	+35°
8	8	PR288/AS/S 0.010 in.	0°
9	9	PR288/AS/S 0.010 in.	-35°
10	10	PR288/AS/S 0.010 in.	0°
11	11	PR288/AS/S 0.010 in.	+35°
12	12	PR288/AS/S 0.010 in.	0°
13	13	PR288/AS/S 0.010 in.	-35°
14	14	PR288/AS/S 0.010 in.	0°
15	15	PR288/AS/S 0.010 in.	+35°

Note: - Balance Layup Concave (C/C) is a Mirror Image of Convex (C/V) Half.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______ Page 1 of 1

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Preforming	20

OPERATION NO.	OPERATION DESCRIPTION
1	Remove laminae kit from freezer and allow a minimum of 1 hour at room temperature before opening the plastic storage bag.
2	Set up mold tool halves which are to be used as preforming fixtures. Cover airfoil surfaces of mold tool halves with teflon tape to prevent contamination of laminae with release agent from mold tool.
3	Lay up C/V laminae according to Laminae Orientation - Sequence Drawing. Be sure all prepreg backing material is removed from laminae during layup.
4	Lay up C/C laminae according to Laminae Orientation - Sequence Drawing. Be sure all prepreg backing material is removed from laminae during layup.
5	Cover laminae assemblies with clean polyethylene film and place in plastic storage bag. Seal bag to prevent ingress of moisture and identify bag. If laminae assemblies are not to be used within 24 hours, return assemblies to 0° F (or lower) cold storage.
6	Sign off routing card for Operation 20 and record preform weight.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION__APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Spar Surface Preparation	30

OPERATION NO.	OPERATION DESCRIPTION
1	Obtain titanium spar. Mask off root and platform areas up to tangent point of airfoil/platform fillet radius on center spar design (TiCore). Mask of exposed leading edge contour of titanium LE spar (TiCom design). Use paper masking tape.
2	Grit blast spar airfoil surfaces using No. 150 aluminum oxide grit at 20 psig for 20 to 30 seconds per side at a nozzle to workpiece distance of 6 inches. Grit blasted surfaces should have a uniform matte finish. Blow off residual powder from spar. Recorded spar serial number and finished weight on route card.
3	Remove masking tape from spar platform and root areas. MEK-cheesecloth clean entire spar. Do not handle spar by airfoil surfaces after solvent cleaning.
4	Obtain PASA-JEL 107M (GE Specification A15D3-B1). Pour PASA-JEL 107M into a glass or plastic container deep enough to cover airfoil portion of spar up to platform. Immerse spar airfoil only in PASA-JEL 107M for 20 to 25 minutes.
5	Remove spar from PASA-JEL 107M and rinse thoroughly with tap water. Before surface can dry, rinse immediately with distilled or de-ionized water. Oven dry spar for 20 to 30 minutes at 130 $\pm 10°$ F. Place spar in a clean plastic bag until ready to use. Next step must be started and primer aplied to spar airfoil bonding surfaces within 2 hours of completion of rinse operation above. Do not handle airfoil surfaces (even with gloves) after etch is complete.
6	Obtain primer - 3M Company XA-3950. If removed from cold storage allow can to thoroughly warm to room temperature before opening. Primer must be thoroughly agitated to re-disperse the pigmentation which settles upon storage (for example, agitation on a paint shaker for 5 minutes).

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION ___ APPROVALS	REVISION ___ APPROVALS

Issue Date ______ Revision No. ______

OPERATION SHEET

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Spar Surface Preparation	30

OPERATION NO.	OPERATION DESCRIPTION
7	Apply a uniformly thin coat of primer (0.1 to 0.3 mils) to the spar airfoil surfaces using a nylon brush or roller. Air dry primed spar for 2 hours, minimum of 75° F. Then place spar in a clean plastic bag. Return sealed bag to 0° F (or lower) cold storage if primed spar is not to be used within 24 hours.
8	Sign off routing card for Operation 30.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___ APPROVALS	REVISION__ APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Titanium Skin Surface Preparation	40

OPERATION NO.	OPERATION DESCRIPTION
1	Obtain formed titanium skins that have been etched down to 0.007 to 0.011-inch thick.
2	Using trim templates, mark cutoff line on formed titanium skins. Cut away excessive titanium from skins using Clauss scissors. File off burred edge resulting from scissors cutting.
3	Grit blast skins both sides using No. 150 alumina grit at 20 psi gage pressure and a nozzle-to-workpiece distance of 6 inches. The thin skin material will tend to curl, so grit blast as follows: a) Lie skins on flat metal suface. b) Grit blast one side for just a few seconds. When curling of the skin starts, stop grit blast and turn skin over. c) Grit blast other side of skin till skin returns to the original contour. Then turn skin over. d) Repeat (b) and (c) till skins no longer curl. e) Then grit blast for approximately 60 seconds per side until skins have a uniform matte surface finish.
4	Solvent clean titanium skins thoroughly with clean cheesecloth and MEK. Handle only with clean white gloves after cleaning.
5	Obtain PASA-JEL 107M (GE Specification A15D3-B1). Pour PASA-JEL 107M into a pyrex or plastic tray deep enough to cover entire skins. Immerse skins in PASA-JEL 107M for 20 to 25 minutes.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION__APPROVALS	REVISION__APPROVALS

Issue Date ______ Revision No. ______

OPERATION SHEET

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Titanium Skin Surface Preparation	40

OPERATION NO.	OPERATION DESCRIPTION
6	Remove skins from PASA-JEL 107M and rinse thoroughly with tap water. Before surface can dry, rinse immediately with distilled or de-ionized water. Oven dry skins for 20 to 30 minutes at 130 $\pm$ 10° F. Cover skins with clean plastic film until ready to use. Next step must be started and primer applied to skin (only the side to get adhesive film) within 2 hours of completion of rinse operation above. Handle prepared surfaces only with clean white gloves.
7	Obtain primer (3M Company XA-3950). If removed from cold storage, allow can to thoroughly warm to room temperature before opening. Primer must be thoroughly agitated to redisperse the pigmentation which settles upon storage. For example, agitation on a paint shaker for 5 minutes would be adequate.
8	Apply a uniform thin coat of primer (oil to 0.3 mils) to the skins (only side where adhesive will be applied) using a nylon brush or roller. Air dry primed spar for 2 hours minimum at 75° F. Cover with clean polyethylene film. Return to 0° F (or lower) storage in sealed plastic bag if not to be used within 24 hours.
9	Sign off routing card Operation 40 and record weight of skins.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Boron/Aluminum Laminae Preparation	50

OPERATION NO.	OPERATION DESCRIPTION
1	Obtain boron-aluminum formed sheets. Four sheets are required: 1 - +15° C/C side 1 - -15° C/C side 1 - +15° C/V side 1 - -15° C/V side
2	Using trim templates, mark cutoff line on formed boron-aluminum sheets. Cut away excess boron-aluminum using Clauss scissors.
3	Solvent clean skins with MEK - cheesecloth wipe. Handle only with clean white gloves after solvent wipe.
4	Obtain fixtures for use as backup for grit blasting of B/Al laminae. Grit blast laminae on both sides using 20 psig and No. 150 alumina grit to obtain a uniform matte finish.
5	Solvent clean skins both sides with MEK - cheescloth wipe.
6	Obtain primer (3M Company XA-3950). If removed from cold storage, allow can to thoroughly warm to room temperature before opening. Primer must be thoroughly agitated to re-disperse the pigmentation which settles upon storage. For example, agitation on a paint shaker for 5 minutes would be adequate.
7	Apply a uniformly thin coat of primer (0.1 to 0.3 mils) to the boron-aluminum laminae both sides using a nylon brush or roller. Air dry primer laminae for 2 hours minimum at 75° F then cover with clean plastic film. Return to 0° F (or lower) cold storage in sealed plastic bag if not to be used within 24 hours.
8	Sign off routing card Operation 50 and record weight of skins.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION__APPROVALS	REVISION__APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Apply Adhesive to Spar, Titanium Skins, and Boron/Aluminum Laminae	60

OPERATION NO.	OPERATION DESCRIPTION
1	Obtain Scotchweld brand adhesive films AF163C and AF3185. If removed from freezer, allow for 1 to 2 hours warmup to room temperature before removing film from plastic enclosure.
2	Obtain preforming fixtures for C/C and C/V blade halves. Clean fixtures thoroughly with MEK and cheesecloth. Take care not to contaminate fixture surfaces that will be in contact with prepared surfaces of boron-aluminum laminae.
3	Obtain primed boron-aluminum laminae. If removed from cold storage, allow to warm up to room temperature before removing from plastic enclosure. Using preforming fixture to support laminae; apply a layer of AF163C adhesive film to the inner surface of C/C2 and C/V2 laminae. Remove C/C2 and C/V2 laminae from preform fixtures. Then apply a layer of AF3185 adhesive film to the inner surface of C/C3 and C/V3 laminae. Store adhesive film covered laminae under clean plastic film until ready to use. If not to be used within 24 hours, place in sealed plastic bag at 0° F (or lower) storage. (Lay-up sequence reference Operation 10, page 2.)
4	Obtain primed titanium skins. If removed from cold storage, allow to warm up to room temperature before removing from plastic enclosure. Put skins in place on preforming fixture. Apply a layer of AF163C adhesive to the inner surface of titanium skins C/C1 and C/V1. Store adhesive film-covered skins under clean plastic film until ready to use. If not to be used within 24 hours, place in sealed plastic bag at 0° F (or lower) storage.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION ___ APPROVALS	REVISION ___ APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Apply Adhesive to Spar, Titanium Skins, and Boron/Aluminum Laminae	60

OPERATION NO.	OPERATION DESCRIPTION
5	Obtain primed spar. If removed from cold storage, allow to warm up to room temperature before removing from plastic enclosure. Apply a layer of AF3185 adhesive film to the spar airfoil surfaces. Store spar under clean plastic film until ready to use. If not to be used within 24 hours, place in sealed plastic bag at 0° F (or lower) storage. (Refer to lay-up sequence Operation 10, page 2.)
6	Sign off routing card Operation 60.

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OPERATION SHEET

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Final Preform Assembly	70

OPERATION NO.	OPERATION DESCRIPTION
1	Obtain prepreg preforms, titanium skins, boron-aluminum laminae, and center spar. If removed from cold storage, allow parts and material to warm to room temperature before opening storage bag.
2	Assemble preform - spar skins and boron-aluminum laminae as follows: a) Obtain mold tool (GM 21778-1) to use as the assembly fixture. Clean mold tool punch airfoil surfaces with MEK and cheesecloth. Mold tool punch is mold half that produces C/V side of blade. b) Put C/V titanium skin in place on assembly fixture locating LE and TE coincident with fixture edges. c) Put C/V boron-aluminum skins (laminae No. 2 and No. 3) in place over titanium skin aligning LE, TE, and tip coincident with edges of fixture. d) Put C/V prepreg preform in place aligning with tip of fixture and proper distance from LE, and TE of fixture as determined from flat laminae layup sheet. e) Put spar in place with spar platform mated to mold tool platform area. f) Put C/C prepreg preform in place. g) Put C/C boron-aluminum skins (luminae No. 2 and No. 3) in place. h) Put C/C titanium skin in place. Then hand press entire assembly together and remove from preform tool.
3	If preform assembly is not to be used within 24 hours, place in sealed plastic bag at 0° F (or lower) storage until ready to use.
4	Sign off routing card Operation 70 and record total preform/spar weight.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ________ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Hot Press and Cure	80

OPERATION NO.	OPERATION DESCRIPTION
1	Set up mold tool (GM 2117-1) in hot platen press.
2	Preheat mold tool to 215 ± 5° F in closed position.
3	Open mold tool and apply carnauba wax release agent to mold tool cavity surfaces. Wipe off excess wax with lint-free cloth. Apply additional release coating of Frekote 33 for double protection against adhesion.
4	Obtain preform assembly from Operation 70. If removed from cold storage, allow to warm to room temperature (~ 2 hours) before opening storage bag.
5	Open preheated mold tool (215° F ± 5° F) and place preform assembly into mold tool. Close press as rapidly as possible to within 1/2 inch of complete closing. Then complete mold tool closing according to the table at right.

Mold Tool Closing Schedule

Elapsed Time, min.	Mold Tool Opening, inch	Maximum Load, lbs
0	0.500	70,000
2	0.250	70,000
4	0.085	70,000
6	0.060	70,000
8	0.048	70,000
10	0.040	70,000
14	0.032	70,000
18	0.025	70,000
22	0.018	70,000
24	0.014	70,000
26	0.010	70,000
28	0.006	70,000
30	Closed	

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Hot Press and Cure	80

OPERATION NO.	OPERATION DESCRIPTION
6	After 30-minute-closing schedule is complete, continue cure in press for 45 ± 5 minutes at 215 ± 5° F. Then raise mold tool temperature to 230 ± 5° F and continue cure for 180 ± 10 minutes at 230 ± 5° F, maximum load 70,000 lbs. During press cure, preheat postcure oven to 275 ± 10° F.
7	At end of press cure cycle, open mold tool, remove molded blade, and transfer immediately to the 275 ± 10° F postcure oven. Postcure blade for 240 ± 10 minutes at 275 ± 10° F.
8	Cool blade in oven to 150° F or lower before removing blade from oven.
9	Sign off routing card for Operation 80 and enclose copy of die closure distance/pressure. Record chart in blade file.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Deflash-Bench-Trim	90

OPERATION NO.	OPERATION DESCRIPTION
1	Break away resin flash from blade periphery taking care not to cause delamination of the composite. Remove remaining flash at leading and trailing edges with No. 80 to No. 120 grit aluminum oxide paper. Record molded blade weight on route card.
2	Trim blade tip (above final trim line) using diamond-tipped cutoff wheel.
3	Bench away excess resin and composite from platform fillet radii using No. 80 to No. 120 aluminum oxide paper. Record trimmed weight on route card.
4	Sign off routing card Operation 90.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION__ APPROVALS	REVISION__ APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______ Page 1 of 2

PART NAME - Center Spar Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-771P01 4013057-780P01	OPERATION Visual Inspect	OPERATION NO. 100

OPERATION NO.	OPERATION DESCRIPTION
1	Visual inspect blade for surface defects. Record defects graphically on visual inspect-sketch sheet. TiCore sketch sheet page 2a, TiCom sketch sheet page 2b.
2	Sign off routing card Operation 100.

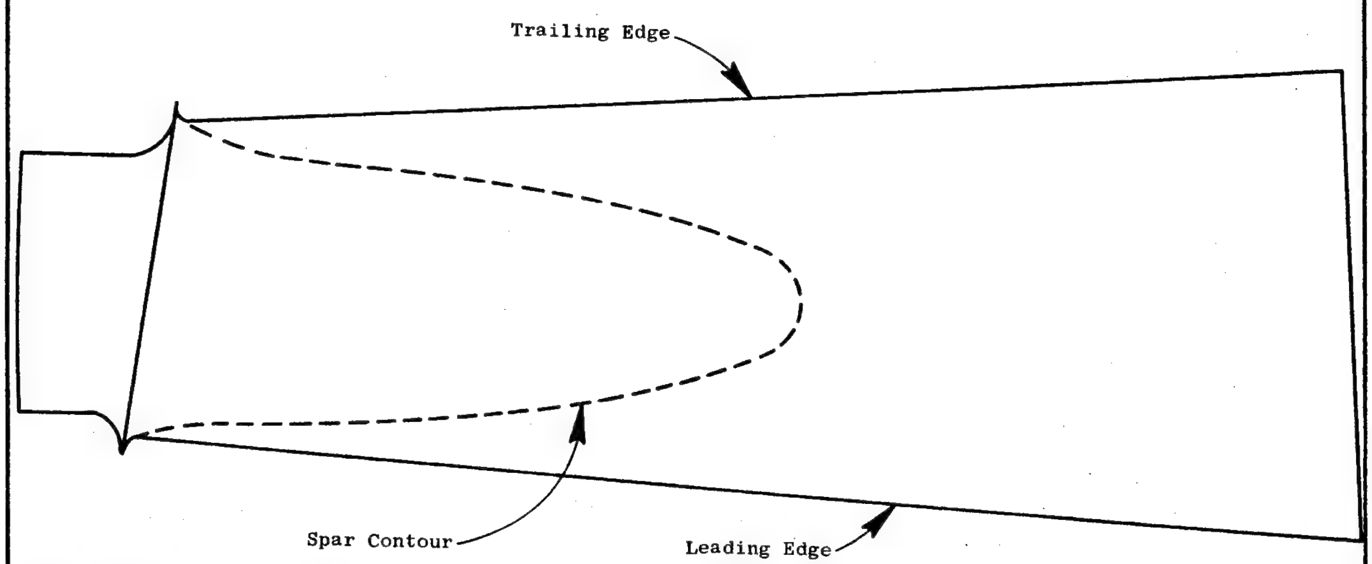
PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION__APPROVALS	REVISION__APPROVALS

OPERATION SHEET

Issue Date ________ Revision No. ______

PART NAME	PART DRAWING NO.	PART SERIAL #	OPERATION	OPERATION NO.
Center Spar (TiCore) Blade, Superhybrid - CF6	4013057-780P01		Visual Inspect	100

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS



Denote Which Surface "Defect" Occurs
C/C - Concave
C/V - Convex

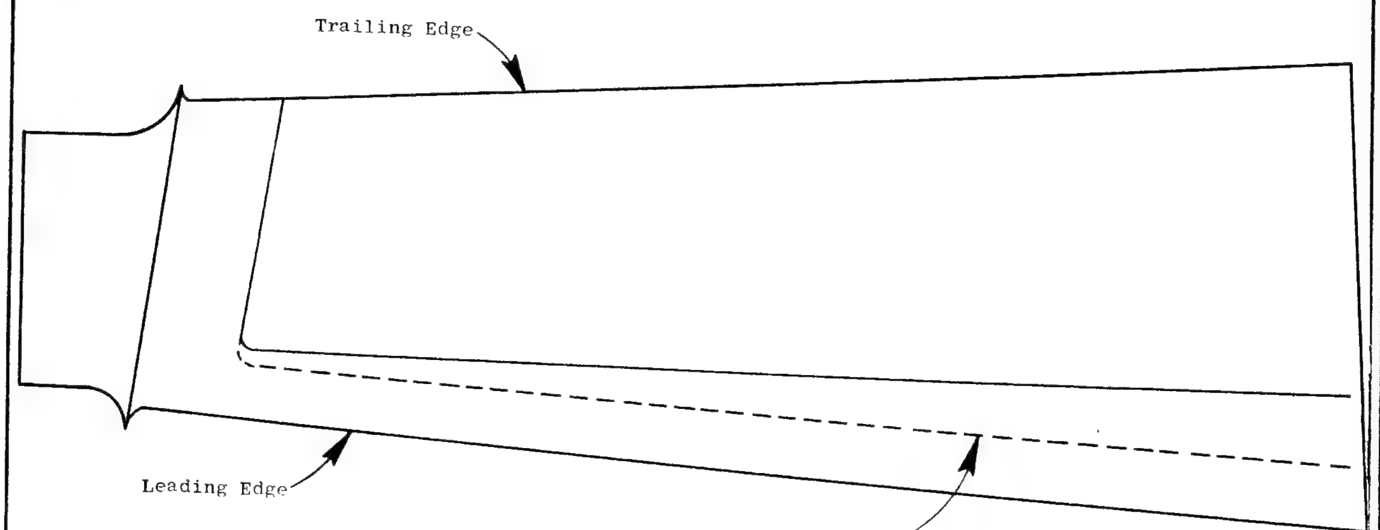
PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION__APPROVALS

OPERATION SHEET

Issue Date ________ Revision No. ______

PART NAME L.E. Spar (TiCom) Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-771P01	PART SERIAL #	OPERATION Visual Inspect	OPERATION NO. 100

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS



Denote Which Surface Defect Occurs
C/C - Concave
C/V - Convex

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION__ APPROVALS	REVISION__ APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Dimensional Inspection	110

OPERATION NO.	OPERATION DESCRIPTION
1	Measure Maximum "T", and record on dimensional inspection sheet. (See page 2 of Operation 110.)

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

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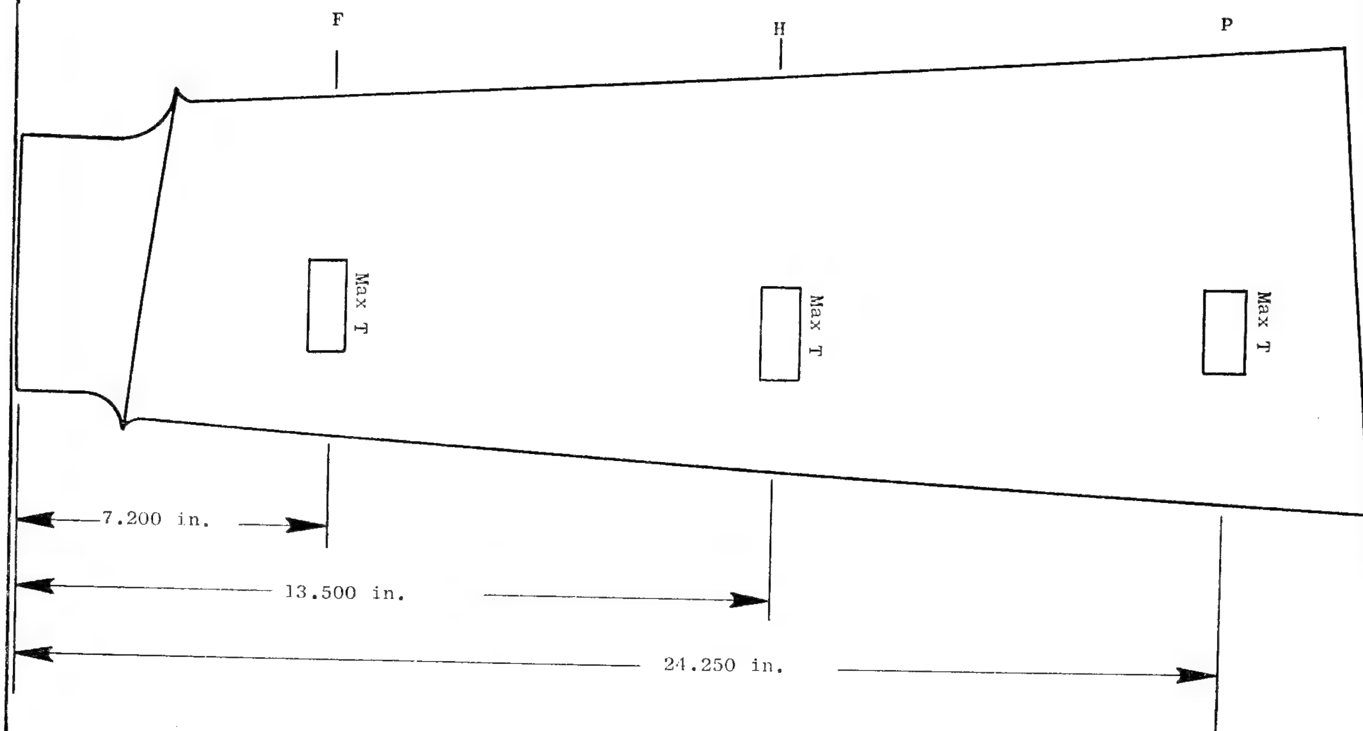
PART NAME Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-771P01 4013057-780P01	PART SERIAL #	OPERATION Dimensional Inspection	OPERATION NO. 110

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS
	

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION __ APPROVALS	REVISION __ APPROVALS

OPERATION SHEET

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PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Ultrasonic Inspect	120

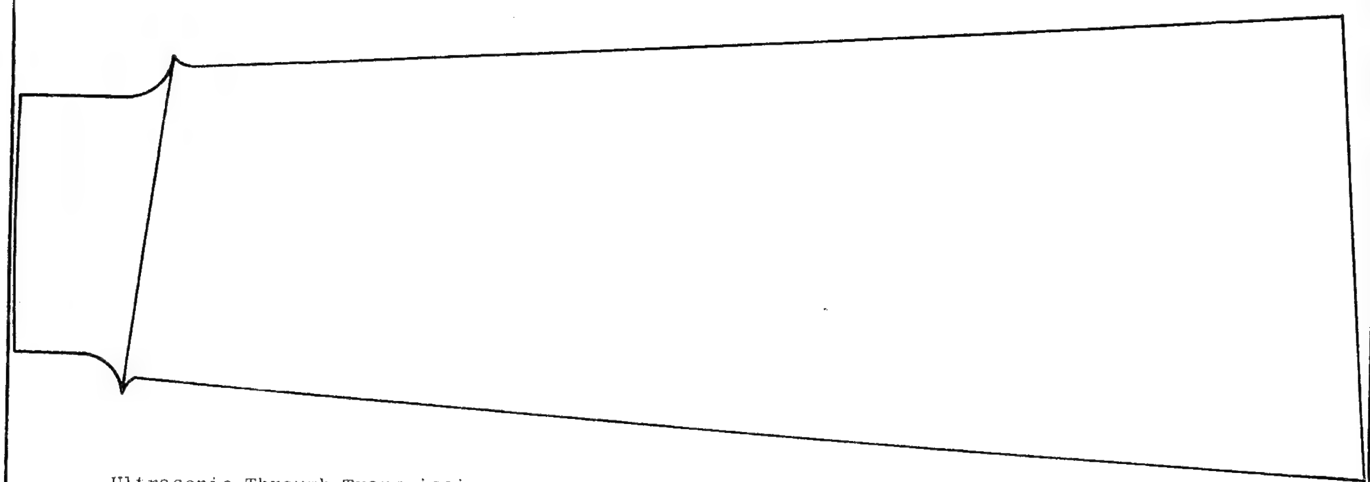
OPERATION NO.	OPERATION DESCRIPTION
1	Ultrasonic inspect using thru transmission hand scan procedure. Record defects (unbonds-delaminations-porosity) in sketch form on inspection sheet. (See page 2 of Operation 120.)
2	Ultrasonic inspect on three dimensional blade scanner. Calibrate equipment by use of TiCore blade RL003 to establish gray scale and equipment sensitivity levels. Previous C-scans of RL003 to be used for comparative purposes. Built-in defects (teflon washers) in RL003 calibration blade should be just visible when correct sensitivity level is achieved.
3	Copy of C-Scan listing pertinent equipment sensitivity settings, serial number, date scanned, and operator's signature to be placed in blade file.
4	Sign off routing card Operation 120.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION__ APPROVALS	REVISION__ APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	PART SERIAL #	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01		Ultrasonic Inspect	120

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS
	

Ultrasonic Through Transmission
Hand Scan Recorded Deffects

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ________ Revision No. ______ Page 1 of 5

PART NAME TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-780P01	OPERATION Application of Wire Mesh	OPERATION NO. 130

OPERATION NO.	OPERATION DESCRIPTION
	General Precautions and Requirements A. Cleanliness of work tables essential B. Record the details required immediately after the operation has been carried out C. Any deviations from the planning must be recorded on the back of the routing card and disposition made before continuing the operation D. Clean plastic or cotton gloves must be used when handling the cleaned blade, tooling surfaces, primed wire cloth, and adhesive
1	Obtain 316SS 100 mesh wire cloth. Record PO No. and Lot No. of wire cloth on routing card.
2	Cut wire cloth from the roll in individual pieces of appropriate length and width and at 45° orientation.
3	Vapor degrease in trichloroethane degreaser for 5 minutes.
4	Vacuum anneal in vacuum furnace 1825° $\pm$ 25° F for 10 minutes.
5	Cool oven under vacuum to 1000° F before backfilling furnace with helium. Allow to cool to maximum of 300° F before opening furnace.
6	Must be performed within 24 hours after Operation 130-5; locate XA3950 primer; allow to heat up to room temperature and fully agitate prior to use.
7	Apply uniform thin coat of primer to wire mesh using a nylon brush and air dry for 2 hours at 75° F minimum.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

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PART NAME TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-780P01	OPERATION Application of Wire Mesh	OPERATION NO. 130

OPERATION NO.	OPERATION DESCRIPTION
8	Select blade and check to ensure LE benching/trimming operations have been completed. Solvent wash entire blade using trichlorethane and cheesecloth. Record blade weight "prior to application of wire mesh" on route card.
9	Form wire mesh over blade leading edge and trim to size as shown on Drawing No. 4013057-989 and remove from blade.
10	Grit blast blade bonding area with No. 150 alumina grit at 20 psi line pressure for 10 seconds C/V side and 30 seconds on C/C side at a nozzle-to-work-piece distance of 6 inches. Mask remaining portion of the blade with paper masking tape allowing 1/8 inch additional exposed area compared to the wire mesh profile.
11	Remove grit dust by lightly dusting with clean lint-free cloth; solvent wipe entire blade with trichlorethane.
12	Prime blade bonding area with XA3950 primer by applying a uniform thin coating and allow to air dry for 2 hours at 75° F.
13	Cut out piece of AF163 adhesive film to a profile slightly oversize compared to the wire mesh and apply to the blade ensuring that there are no wrinkles or air pockets and that the film is not stretched.
14	Place formed wire mesh over the blade leading edge on top of the adhesive film. Work mesh into adhesive film and finally trim excess adhesive film leaving 1/16 to 1/8 inch extending beyond the edge of the mesh.
15	Apply 1-inch-wide strip of teflon masking tape on blade adjacent to wire mesh.
16	Apply one layer of perforated teflon film over wire mesh.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION __ APPROVALS	REVISION __ APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-780P01	OPERATION Application of Wire Mesh	OPERATION NO. 130

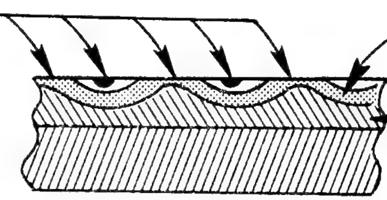
OPERATION NO.	OPERATION DESCRIPTION
17	Position one ply of No. 120 grass cloth bleeder fabric over the bond area and extending 1 to 2 inches over the blade surface and hold in place with teflon tape.
18	Position one ply of brown teflon coated bleeder cloth over remainder of the blade overlapping onto the No. 120 glass cloth.
19	Place thermocouple at approximately midspan height close to wire mesh and tape in place with teflon tape.
20	Prepare autoclave bag of nylon film and seaming tape. Place blade assembly into bag with glass bleeder fabric wrapped around vacuum line. Check for leaks by evacuating the bag under vacuum ensuring no wrinkling of the bag over the wire mesh area.
21	Autocalve cure assembly a) Apply full vacuum pressure to the bag and 40 psi autoclave pressure. b) Heat autoclave to 265° F $\pm 5°$. c) When temperature of blade T/C reaches temperature, hold conditions constant for 60 minutes ± 5 minutes. d) Cool under pressure and vacuum until temperature reaches 150° F before removing the part. e) Enclose copy of cure time/pressure/temperature chart in blade file.
22	Bench away excessive adhesive from surface of wire mesh until wire mesh is completely exposed to produce nickel plating sites.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013-57-780P01	OPERATION Application of Wire Mesh	OPERATION NO. 130

OPERATION NO.	OPERATION DESCRIPTION
22(cont'd)	 Finally, sand finish with No. 180 aluminum oxide paper and wipe entire blade with cheesecloth and trichlorethane
23	Inspect wire mesh surface under 5X magnification and record any defects on the back of the routing card. Minor defects may be repaired with Eccobond solder 57C. Cure for 1 hour at 275° F. Maximum size of defect 0.125 x 0.125 inch.
24	Dimensionally inspect LE contour with form templates at Sections NN, JJ, and FF. (See inpsection record sheet - Operation 130.)
25	Weigh blade and record weight on route card.
26	Sign off routing card Operation 130.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___ APPROVALS	REVISION__APPROVALS

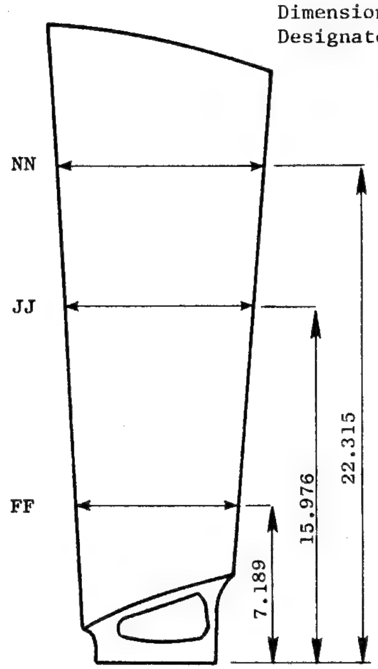
OPERATION SHEET

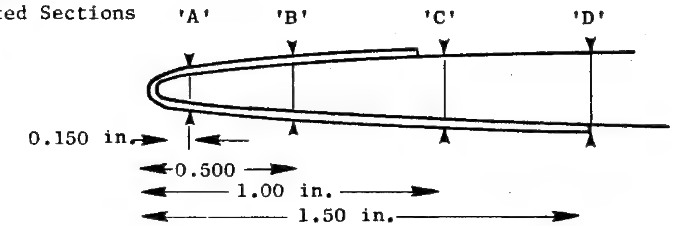
Issue Date ________ Revision No. ________

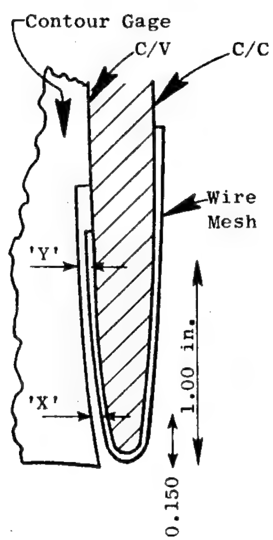
PART NAME TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-780P01	OPERATION Application of Wire Mesh	OPERATION NO. 130

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS

Record all Chordal Dimensions at Designated Sections







Airfoil Section	Record of Blade Leading Edge Maximum Thickness			
	'A'	'B'	'C'	'D'
Section FF				
Section JJ				
Section NN				

Airfoil Section	Gap Between Contour Gage			
	'X'		'Y'	
	C/C	C/V	C/C	C/V
Section FF				
Section JJ				
Section NN				

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

Page 1 of 2

PART NAME TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-780P01	OPERATION Nickel Plating	OPERATION NO. 140

OPERATION NO.	OPERATION DESCRIPTION
1	Supply blade and plating rack to Hohman Plating Company, Dayton, Ohio.
2	Plating of blade to be performed in accordance with GE Specification 4013192-654.
3	Visually inspect plating and record any defects on inspection sheet (Page 2 of 2 - Operation 140).
4	Dimensionally inspect chordal dimensions and record on inspection sheet. Check chordal dimension prior to plating (Operation 130, page 5) and record effective nickel plate thickness.
5	Sign off Operation 140 on route card for visual and dimensional inspection.

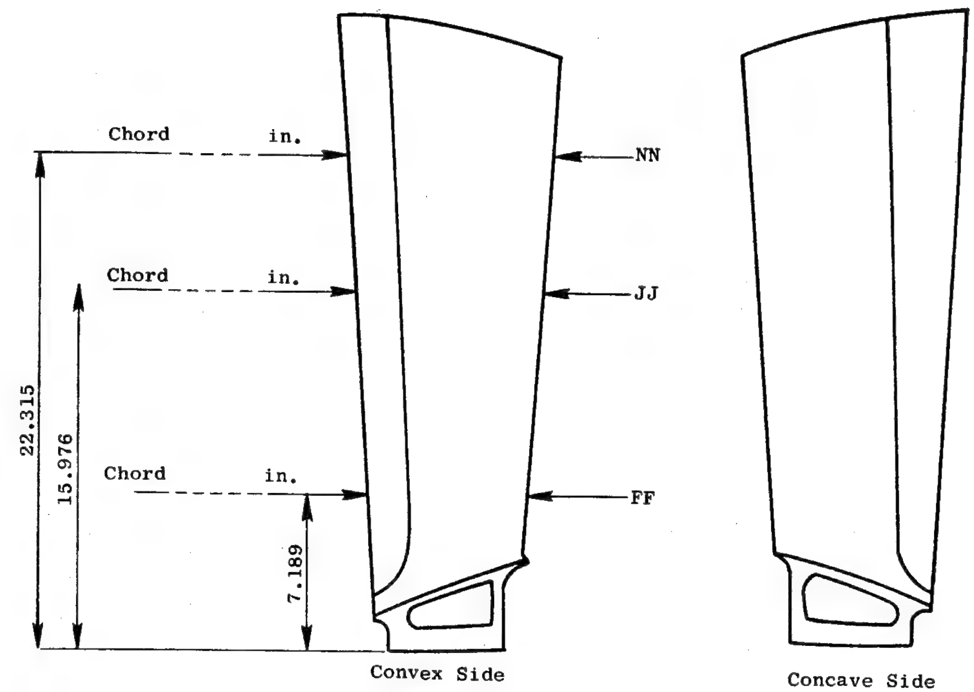
PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION__APPROVALS

OPERATION SHEET

Issue Date ________ Revision No. ______

PART NAME TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-780P01	PART SERIAL #	OPERATION Nickel Plating	OPERATION NO. 140

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS



Compare Chordal Dimensions from Opn. 130 (p. 6) and Record Effective Nickel Plate Thickness Below:

Section	Leading Edge Nickel Plate Thickness (B/P 0.065")
FF	
JJ	
NN	

1. Visual inspect nickel plating and record all defects.
2. Record chordal dimensions at designated sections.

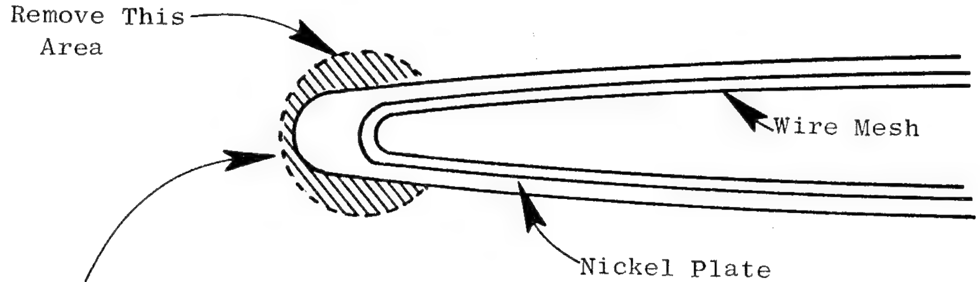
PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

Page 1 of 1

PART NAME TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-780P01	PART SERIAL #	OPERATION Leading Edge Benching	OPERATION NO. 150

OPERATION NO.	OPERATION DESCRIPTION
1.	Bench leading edge nose contour to remove bulbous buildup produced during plating process to produce smooth aerodynamic blend with remainder of plated leading edge.  Maintain chordal dimension - Do not remove any stock from extreme leading edge unless oversize Ref. Dimensional Inspection Operation 140-4. Remove surplus material by filing and hand sanding - No mechanical equipment to be used. Lightly grit blast plated area to produce uniform surface finish.
2.	Sign off route card for Operation 150.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION__APPROVALS	REVISION__APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______ Page 1 of 1

PART NAME TiCore Blade, Superhybrid - CF6	PART DRAWING NO. 4013057-780P01	OPERATION Leading Edge NDE Inspection	OPERATION NO. 160

OPERATION NO.	OPERATION DESCRIPTION
1	Ultrasonically inspect nickel-plated LE area using three dimensional blade scanner. Calibrate equipment by making a partial scan of TiCore Blade RL003 calibration blade with built-in defects.
2	Copy of C-scan record listing pertinent equipment sensitivity settings, blade serial number, date scanned, and operator's signature to be placed in the blade file.
3	Sign off routing card Operation 160.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Final Inspection	170

OPERATION NO.	OPERATION DESCRIPTION
1	Visually inspect entire blade for any damage which may have occurred during processing. Record any damage or defects on copy of Page 4 of Operation 170 for each individual blade. Sketch position and describe type of defect.
2	Dye penetrant inspection of blade tip. a) Check that blade has been finally trimmed to length. b) Apply spot check dye penetrant (Magnaflux Corporation SKL-HF) and developer (SKD-NF) to the extreme tip of the blade. c) Sketch dye penetrant indications on copy of Page 4 of Operation 170.
3	Dimensionally inspect blade a) Chordal dimensions b) LE thickness c) Overall length (a–c: Record details on work sheet (Page 4)) d) Center of gravity - record details on worksheet (Page 4)
4	Final pan weight. Weigh the blade and record the final weight on the route card.
5	Check documentation Ensure that all documentation is available for MRB review and is compiled in each separate blade file. a) Check that all operations have been signed off and dated on the route cards. b) Check availability of process control records.

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01	Final Inspection	170

OPERATION NO.	OPERATION DESCRIPTION
5(cont'd)	c) Check that statistical weights are recorded. d) Check availability of NDE C-scan records. e) Check availability of visual inspection and dimensional inspection work sheets.
6	Sign off Operation 170 on route card.

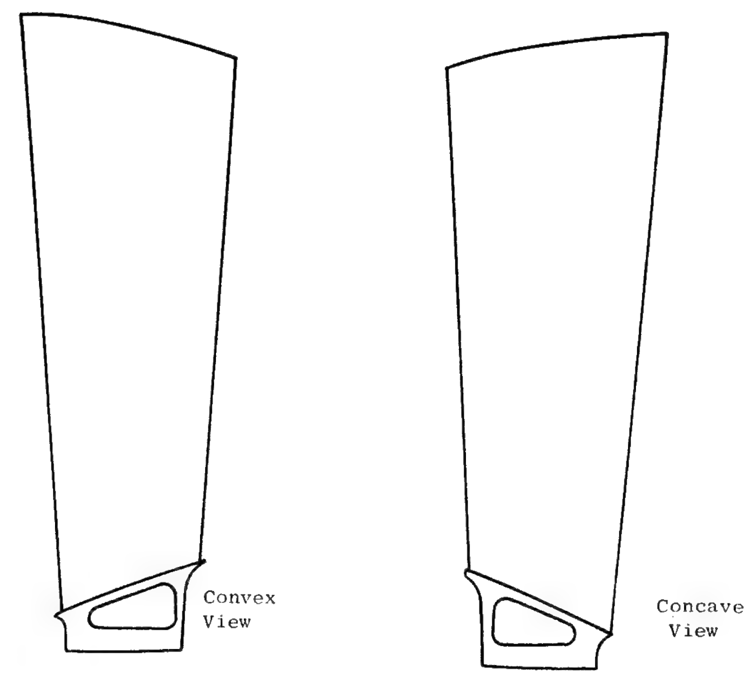
PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___ APPROVALS	REVISION__ APPROVALS

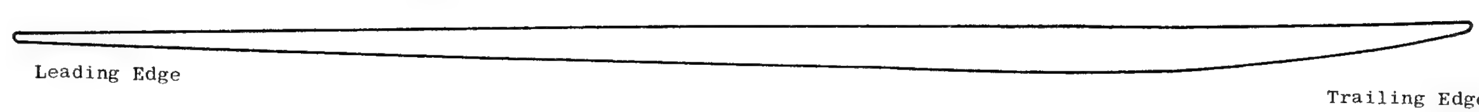
OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	PART SERIAL #	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01		Final Inspection	170

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS
170-1	Visual Inspection
170-2	Dye Penetrant Inspection - Blade Tip





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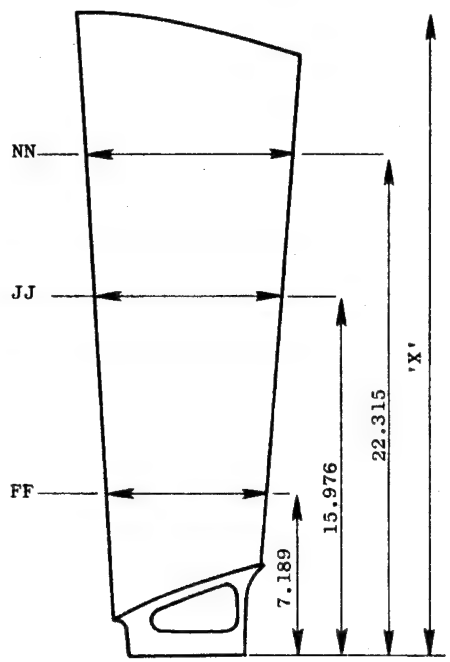
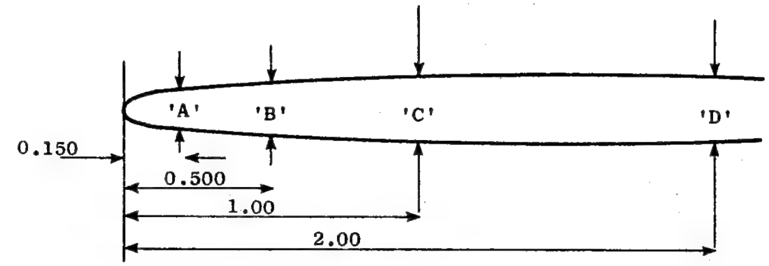
OPERATION SHEET

Issue Date ________ Revision No. ______

PART NAME	PART DRAWING NO.	PART SERIAL #	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01		Final Inspection	170

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS
170-3	





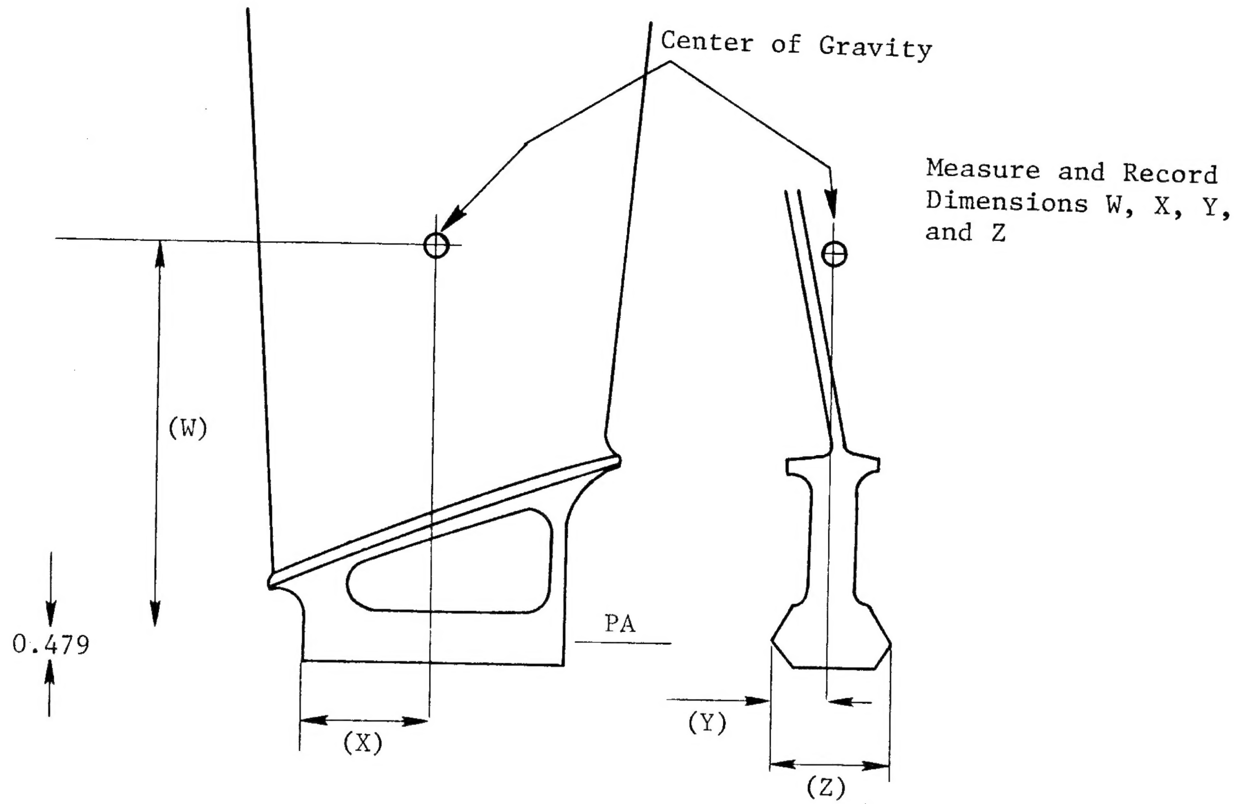
Airfoil Section	Leading Edge Thickness (in) 'A'	'B'	'C'	'D'	Chordal Dimension (in)	Section Max. Thickness (in)	Overall Length 'X' (in)
FF							
JJ							
NN							

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	PART SERIAL #	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01		Final Inspection	170

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS
170-3	

PREPARED BY	PROGRAM ENGR	QC ENGINEER	DESIGN ENGR	REVISION___APPROVALS	REVISION___APPROVALS

OPERATION SHEET

Issue Date ______ Revision No. ______

PART NAME	PART DRAWING NO.	PART SERIAL #	OPERATION	OPERATION NO.
Blade, Superhybrid - CF6	4013057-771P01 4013057-780P01		MRB Review	180

OPERATION NO.	SKETCHES - SPECIAL INSTRUCTIONS

Operation No.	Item	Detail	Review Board Decision									Comments
			Accept			Pending			Reject			
			M	E	Q	M	E	Q	M	E	Q	
100	Visual Inspection	Skin Distortion Skin Spar Transition LE/TE Condition										
110	Dimensional Inspection	Maximum Thickness										
120	Ultrasonic Inspection	Hand Scan C-Scan										
140	Nickel Plating (TiCore Design Only)	Visual Dimensional										
150	LE Benching (TiCore)	Visual										
160	Ultrasonic Insp TiCore LE	C-Scan										
170	Final Inspection	Visual Dye Penetrant Tip Dimensional										
Material QA	PR288/AS(80)/S(20) AF163 Adhesive AF3185 Adhesive Boron-Aluminum Titanium Foil	Physical Prop. Mechanical Prop. Lap Shear Lap Shear Fiber Degredation Ti 6-4										Acceptance Signatures Design (E) ______ Manufacturing (M) ______ Quality (Q) ______ Grade

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